Washington State Department of Transportation

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek (WDFW ID 990773): Final Hydraulic Design Report

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1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 8 crossing of an unnamed tributary to Mox Chehalis Creek at milepost (MP) 9.10 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 990773) and has an estimated 8,140 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing and avoidance of the stream crossing was determined to not be viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT is proposing to replace the existing crossing structure with a culvert structure designed using the stream simulation design methodology.

The crossing is located in Grays Harbor County, 2 miles east of McCleary, Washington, in WRIA 22. The highway runs in an east-west direction at this location and is about 150 feet from the confluence of Unnamed Tributary to Mox Chehalis Creek with Mox Chehalis Creek. Unnamed Tributary to Mox Chehalis Creek generally flows from north to south beginning over 3,000 feet upstream of the SR 8 crossing (see Figure 1 for the vicinity map).

The proposed project will replace the existing 4-foot-wide by 140-foot-long cast-in-place concrete culvert with a 18-foot-wide by 135.5-foot-long precast concrete culvert designed to accommodate a minimum hydraulic width of 18 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a).

The original Preliminary Hydraulic Report for this site was completed in 2019 by a different engineering group. The requirements and organization of this document have since changed. This Final Hydraulic Report has updated the preliminary work to the extent practical using provided existing condition information from the earlier work on this site. The preliminary data does not always provide the level of detail that is now expected for fish passage work, and so this report may not contain all the information that is provided in more recent reports.

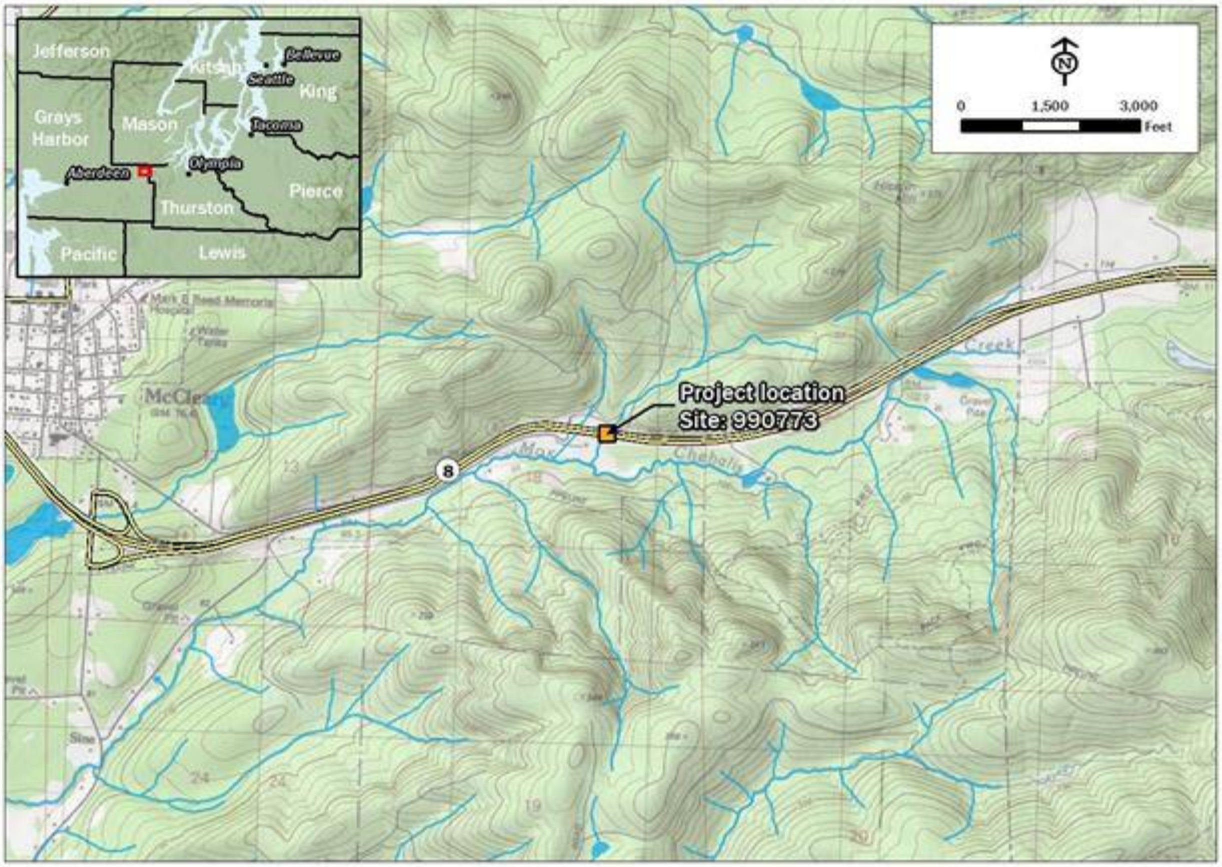

Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, and past records like observations, maintenance, and fish passage evaluation.

2.1 Site Description

The Unnamed Tributary to Mox Chehalis Creek was surveyed by WDFW in December 2005, and they estimate 8,140 linear feet of potential habitat is available upstream of Culvert 990773. However, there is a second culvert located approximately 120 feet upstream of Culvert 990773 under McCleary Road, which is referred to as the “McCleary Culvert” in this report. The McCleary Culvert was determined to be a barrier to fish passage due to hydraulic drop, limiting the potential habitat gain to approximately 50 feet. The reach upstream of the McCleary Culvert is 14 percent pool and 86 percent riffle over the 300 linear feet of stream surveyed.

2.2 Watershed and Land Cover

The Unnamed Tributary to Mox Chehalis Creek drains an estimated 388 acres of designated timberland with pockets of agricultural land, low-density residential area and second growth forest. There are areas of timber harvest in nearby basins, visible on Figure 2. The stream flows into Mox Chehalis Creek approximately 550 feet downstream of the crossing at SR 8. Elevations in the watershed range from 451 to 325 feet above mean sea level (USGS 2019). A land cover table and figure were not provided in the preliminary report, though general land cover can be seen in Figure 2.

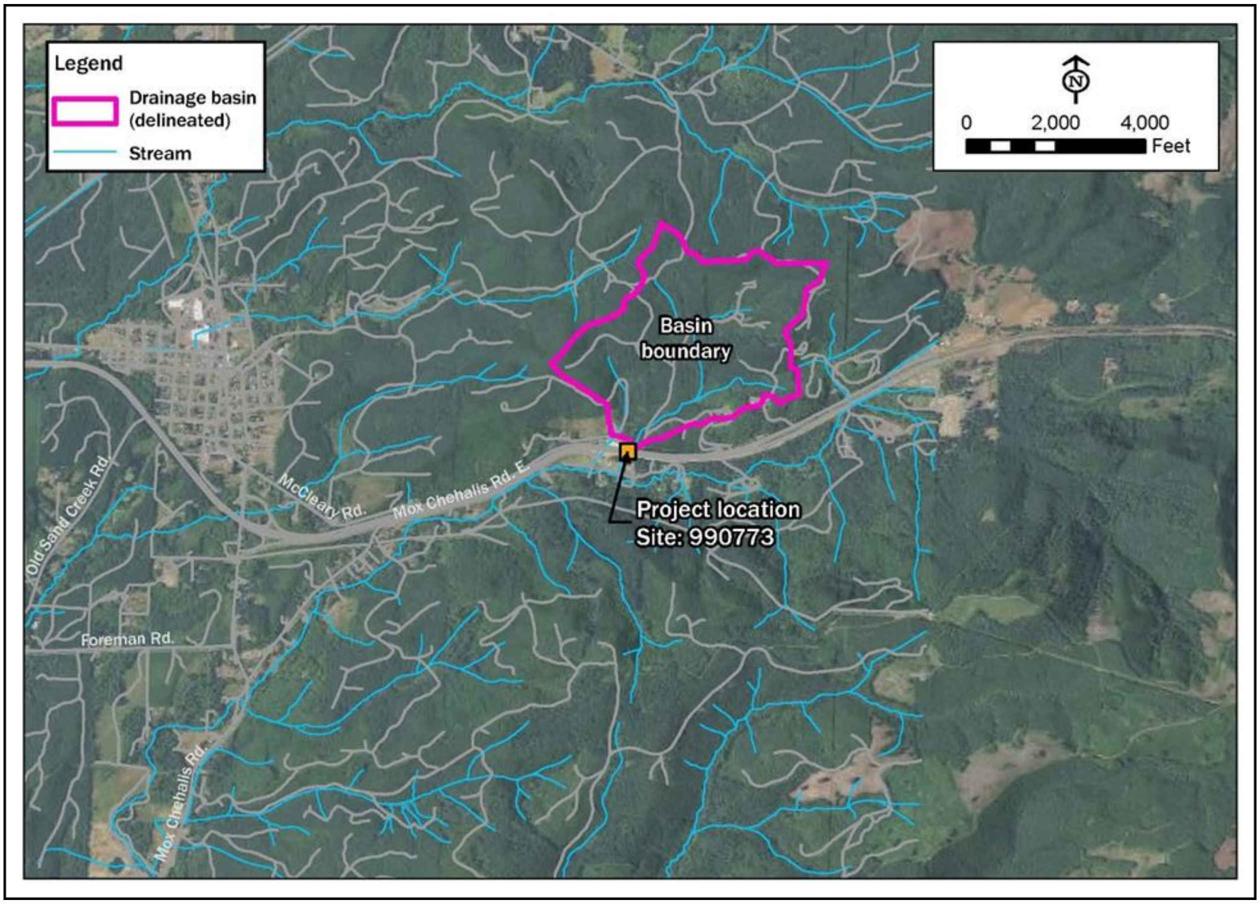

Figure 2: Watershed map

2.3 Geology and Soils

The entire watershed area upstream of Culvert 990773 overlies Eocene era sediments. These are identified as “Evc” on Figure 3, representing the Crescent Formation basalt of the lower to middle Eocene Epoch. Basalts are an igneous rock, and this Eocene foundation pre-dates the more recent glaciations of Puget Sound. This watershed is at the edge of the mapped extent of the pre-late Wisconsin Cordilleran Ice Sheet. The upland area would have been covered in ice and glacial sediments at one time and has since eroded to the base level basalt. The change in geology to a Pleistocene era sediment occurs downstream of Culvert 990773, at an elevation of approximately 130 feet. The sediment mapped as “Qgo” (Figure 3) is recessional outwash from the late Wisconsin glaciation during the Pleistocene Epoch. These consist of poorly to moderately sorted gravel and sand with local areas of coarser and finer sediments. They were deposited by the Puget lobe of the Cordilleran glacier, and in the area of the Mox Chehalis Creek valley often include andesitic and basaltic clasts.

Soils in the watershed upstream of Culvert 990773 are of a consistent character, reflecting the uniformity of the underlying geology (Figure 4). The unnamed stream flows over Tebo Silt Loam, which has a moderate infiltration rate (Table 1). These soils are competent over a large range of slopes. The area immediately downstream of Culvert 990773 and corresponding to Pleistocene outwash is covered in gravelly loams. The unnamed stream and SR 8 pass over the Lyre Variant Very Gravelly Sandy Loam, which expresses at low slopes and has a low infiltration rate. Farther downstream, approaching the confluence with Mox Chehalis Creek, the soil transitions to the Carstairs Very Gravelly Loam and has a high infiltration rate. At the confluence with Mox Chehalis Creek the soil type is Chehalis Silt Loam

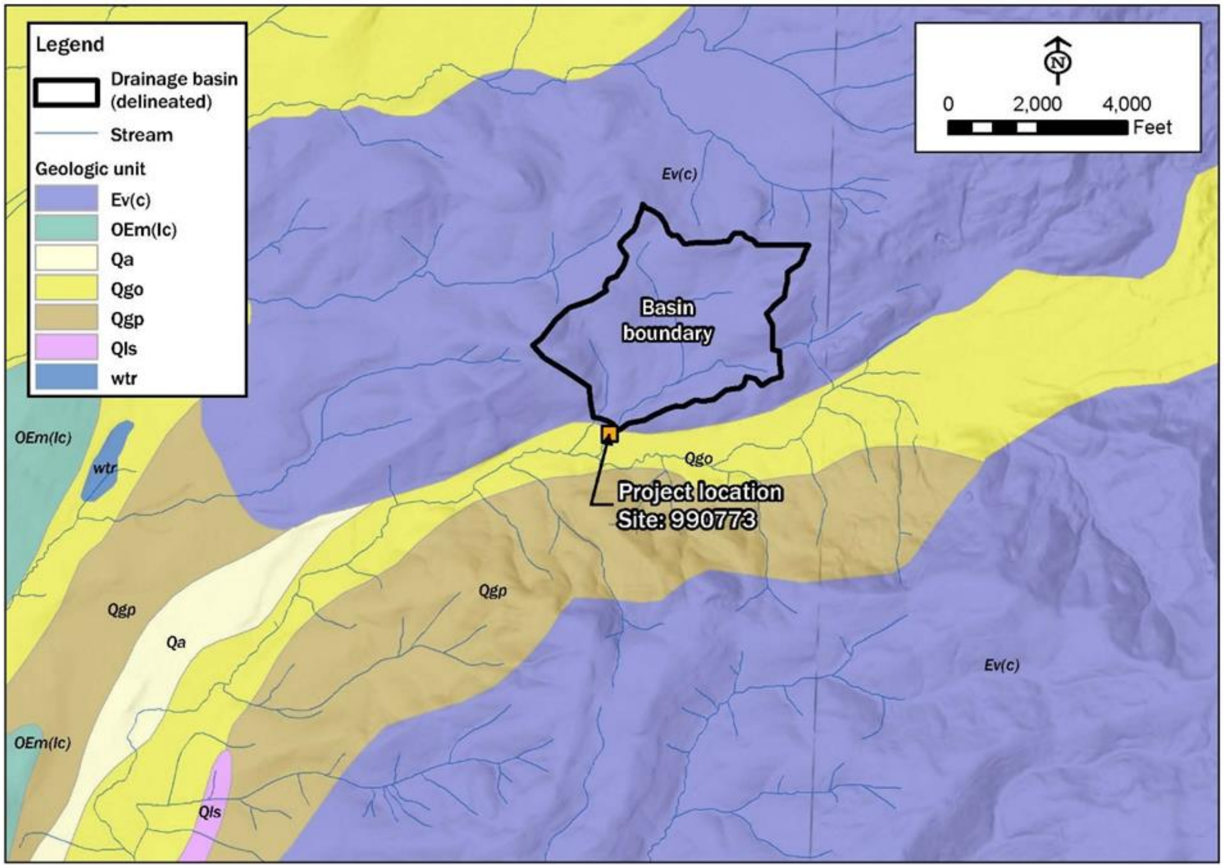

Figure 3: Geologic map

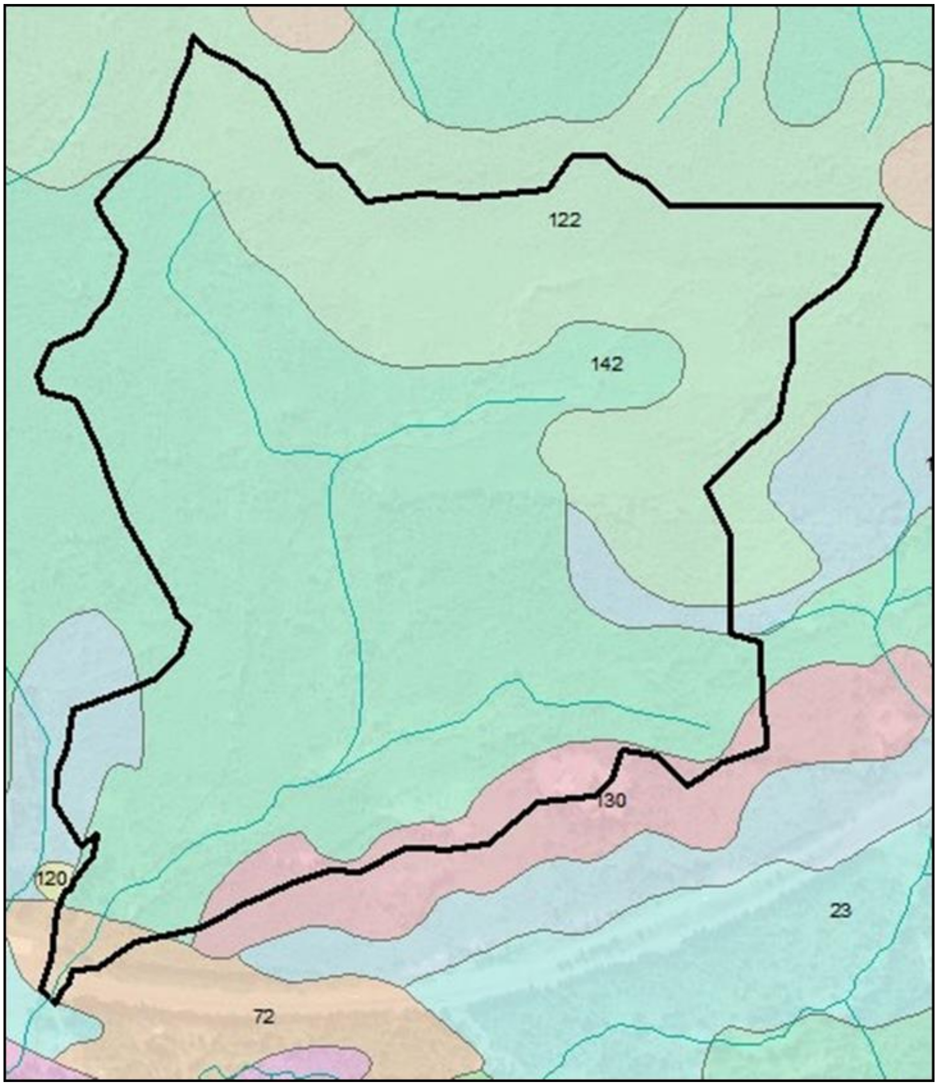

Figure 4: Soils map

Table 1: Soils in watershed

Map Unit Symbol (see Figure 4)	Soil Unit Name	Slope	Hydro Group
72	Lyre Variant Very Gravelly Sandy Loam	0 to 3	C
142	Tebo Silt Loam	5 to 30	B
23	Carstairs very gravelly loam	1 to 8	A
30	Chehalis Silt Loam	0 to 3	B

2.4 Fish Presence in the Project Area

Table 2 provides a list of native fish potentially found in the Unnamed Tributary to Mox Chehalis Creek. The stream may support coho (Oncorhynchus kisutch) and chum salmon (Oncorhynchus keta), and steelhead (Oncorhynchus mykiss), coastal cutthroat (Oncorhynchus clarkii), and resident rainbow trout (Oncorhynchus mykiss). Of these, Puget Sound Distinct Population Segment steelhead trout is a threatened species under the Endangered Species Act of 1973. In Washington State, coho and chum salmon are on the Priority Habitat and Species list defined by WDFW.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho salmon (*Oncorhynchus kisutch*)	Presence	Fish Passage Report (WDFW)	Not warranted
Chum salmon (*Oncorhynchus keta*)	Presence	Fish Passage Report (WDFW)	Not warranted
Steelhead (*Oncorhynchus mykiss*)	Presence	Fish Passage Report (WDFW)	Federally Threatened
Coastal cutthroat trout (*Oncorhynchus clarkii*)	Presence	Fish Passage Report (WDFW)	Not warranted
Resident rainbow trout (*Oncorhynchus mykiss*)	Presence	Fish Passage Report (WDFW)	Not warranted

Fish presence and use of the unnamed stream is uncertain. Site investigations in June through August 2019 encountered a dry channel downstream of the McCleary Culvert plunge pool that prevents fish use seasonally. The creek would likely be used as non-natal rearing during the fall and winter when sufficient flow is present prior to outmigration in the spring for coho salmon and as non-natal rearing and refuge during fall, winter and spring for steelhead, coastal cutthroat, and resident trout. Chum salmon out migrate shortly after emergence in the spring and may use the non-natal stream as a holding area but would likely not use it as an extended rearing habitat.

2.5 Wildlife Connectivity

The one-mile-long segment that Unnamed Tributary to Mox Chehalis Creek falls in ranked low priority for Ecological Stewardship and low priority for Wildlife-related Safety by WSDOT Headquarters (HQ) ESO. Adjacent segments to the west and east ranked medium. A wildlife connectivity memorandum will not be provided at this site and additional width or height has not been recommended by WSDOT HQ ESO for wildlife connectivity purposes.

2.6 Site Assessment

2.6.1 Data Collection

The site assessment was performed over three site visits attended by the project geomorphologist and project fisheries biologist. On June 28, 2019, a reconnaissance level investigation was conducted to determine level of effort and obtain an overview of the project area. The upstream reach of the site was investigated on August 6, 2019, and the downstream reach was investigated on August 23, 2019. During these site visits the immediate areas around the creek were walked, and data was collected to help support the streams design.

Survey was performed by WSDOT in July 2019. About 1200 linear feet of stream was surveyed. The survey extends approximately 440 feet upstream of SR 8 and includes the McCleary Culvert. Approximately 550 feet downstream of SR 8 was also surveyed.

During the site visits four bankfull width measurements were taken, two upstream and two downstream (see Section 2.7.2). Two pebble counts were also collected, one upstream and one downstream (see Section 2.7.3).

2.6.2 Existing Conditions

During initial reconnaissance on June 28, 2019, it was discovered that the McCleary Culvert appears to exert a significant influence on the channel morphology, hydraulics, and sediment transport processes in the vicinity of the SR 8 crossing. The McCleary Culvert is a concrete box structure with dimensions of 4 feet wide, 4 feet high, and 70 feet long. A plunge pool has formed at the outlet, which is perched 3.5 feet above the pool and has eroded over 1.1 feet beneath a concrete apron (Figure 5).

Culvert 990773 under SR 8 is a 4-foot by 4-foot concrete box culvert with a metal trash rack at the entrance, indicating a potential issue with debris accumulating from upstream reaches. Culvert 990773 has a length of 140 ft and a slope of 0.81%.

On August 6, 2019, the team investigated the upstream reach of the unnamed tributary beginning approximately 250 feet upstream of the McCleary Culvert. Upstream of both culverts, the channel has a moderate gradient as it flows through forested habitat with large woody material (LWM) in several locations that is helping to create diverse habitat conditions (Figure 6). Several resident fish were observed within pools upstream of the McCleary Culvert.

The plunge pool at the McCleary Culvert outlet is eroded into the fill that was apparently placed when the McCleary Culvert was installed. A record of the original streambed elevation is preserved in the side walls of the plunge pool indicating that the channel eroded until regaining its original bed and elevation (Figure 7). Roughly 15 feet from the end of the plunge pool the channel became dry at the time of the site visit and remained dry from there to the confluence with Mox Chehalis Creek (Figure 8). Channel slope is adverse within the plunge pool and recovers to average 1.95 percent to Culvert 990773. From the plunge pool the channel continues downstream to Culvert 990773 at SR 8 (Figure 9). It appears that the fill placed when the McCleary Culvert was installed has since eroded downstream and deposited approximately 0.7 feet of gravel and sand within Culvert 990773 (Figure 10).

In addition to the main channel culverts, another small culvert crosses under McCleary Road west of the main channel McCleary Road culvert. This culvert brings in flow from additional hillslopes and private property and discharges it to the main channel just upstream of Culvert 990773. This culvert is a 26-inch round concrete pipe under 3.5 feet of fill. There is a significant slope to this small culvert, and the downstream end is perched 10 inches above its channel. The confluence of ditched flow from this culvert to the main channel is where a bankfull width of 10.6 feet was measured.

Figure 5: Plunge pool immediately downstream of McCleary Culvert and upstream of Culver 990773. Note the large gravel visible at the water level.

Figure 6: Tributary upstream of McCleary Culvert in forested reach.

Figure 7: Closeup of bank of plunge pool at McCleary Culvert outlet.

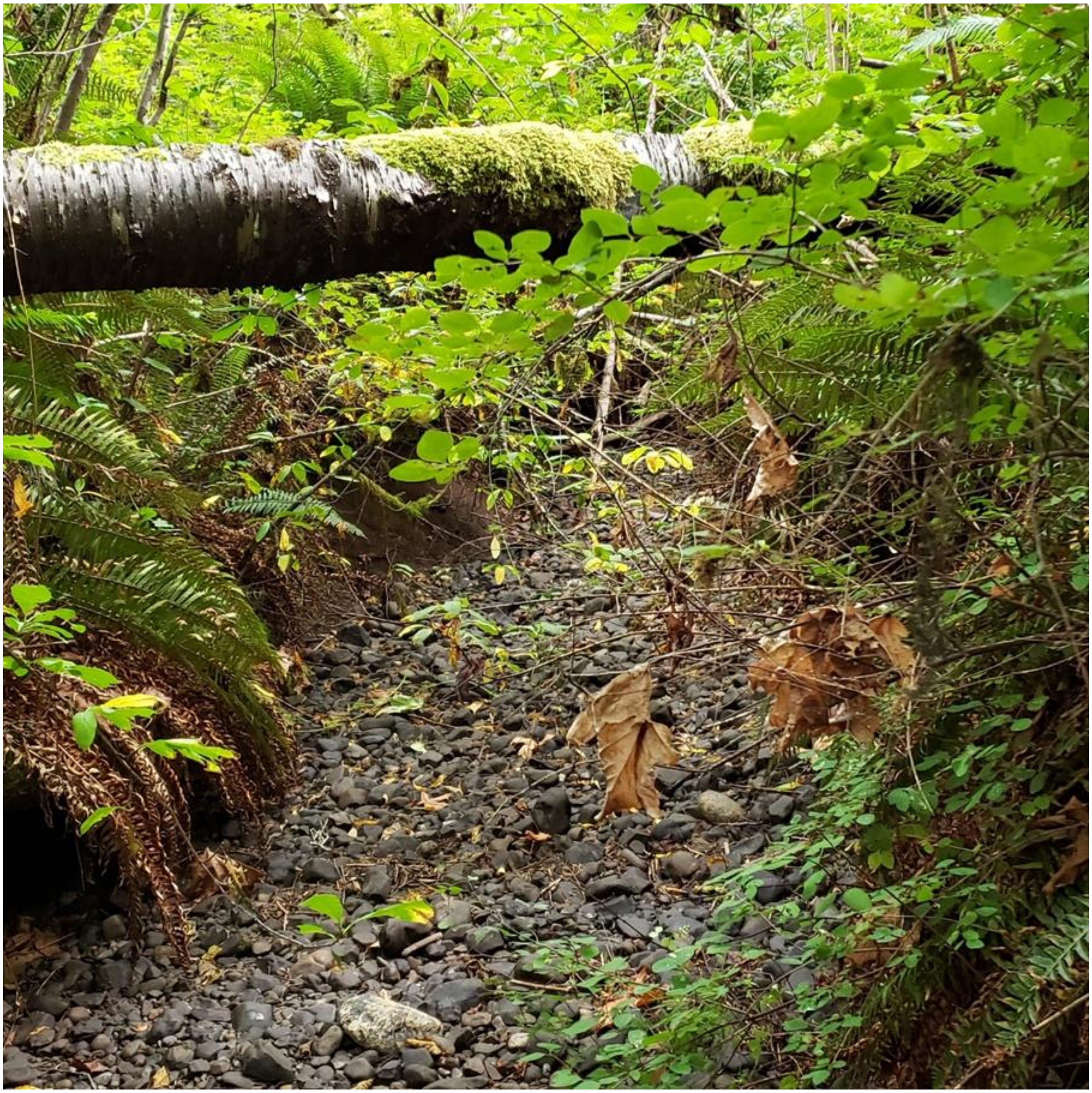

Figure 8: Dry channel bed between McCleary Culvert and Culvert 990773

Figure 9: Tributary bed downstream of McCleary Culvert and upstream of Culvert 990773

Figure 10: Sediment deposit within Culvert 990773

During the third site visit on August 23, 2019, the downstream portion of the unnamed stream was assessed from the outlet of Culvert 990773 to the confluence with Mox Chehalis Creek. Immediately downstream of Culvert 990773 the unnamed stream is in a heavily vegetated area. The stream then flows through a narrow riparian area in an otherwise cultivated landscape (Figure 11). This reach of the stream is in a stable channel with natural banks and an average 2.6 percent slope. The stream bed in this area has a consistent gravel distribution with no fining or coarsening with distance, and there is no surface armoring. There is an alternate bar formation in the bed pattern. Together, these conditions indicate a bed that is easily fully mobilized during higher flows.

As the channel passes between two wire fences, it is 9.5 feet wide and 3 feet deep. In this reach the channel has overhanging vegetation but low banks and a gravel and sand channel bed. The reach was dry when visited. The unnamed stream continues beyond these fences through a maintained (mowed) lawn with a buffer of predominantly blackberry bushes for a length of approximately 300 feet (Figure 11). Another culvert, 36 inches in diameter and made of corrugated metal, spans LaBelle Lane approximately 475 feet downstream of Culvert 990773 and only 80 feet upstream of the confluence with Mox Chehalis Creek. There is 0.2 foot of gravel deposition within the LaBelle Lane Culvert. The channel ends at the confluence with Mox Chehalis Creek (Figure 12). Downstream of LaBelle Lane, the low gradient channel is 9 feet wide and 2.3 feet deep.

Figure 11: Dry tributary bed downstream of Culvert 990773 where it passes between lawns.

Figure 12: Stream channel amid reed canarygrass prior to confluence with Mox Chehalis Creek

2.6.3 Fish Habitat Character and Quality

The Unnamed Tributary to Mox Chehalis Creek offers a mix of fair to good quality non-natal rearing habitat for salmonids.

The habitat upstream of Culvert 990773 is limited by the presence of the impassable McCleary Culvert. Upstream of McCleary Culvert, the habitat transitions from fair to good conditions. Some fish, likely resident trout species, were observed in pools during the August site investigation. Between the McCleary Culvert and the inlet to Culvert 990773 at SR 8, the habitat is of fair quality as it transitions from forested to disturbed.

Around the crossing area of Culvert 990773 fish would not be present during the summer months when flow is absent or diminished through the unnamed tributary.

Downstream of Culvert 990773, the habitat quality is fair and transitions to poor as the channel enters an area of cultivated lawns. Although the channel was dry in this reach during site investigations in summer 2019, no pools were evident.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

There are several natural accumulations of LWM in the channel upstream of Culvert 990773 and the riparian forest offers clear potential for ongoing LWM recruitment in this reach. The LWM has created pool-riffle habitat utilized by resident fish, observed during the site assessment. The immediate crossing area of Culvert 990773 is disturbed with riparian vegetation consisting of a mix of native and nonnative invasive species. The reach downstream of Culvert 990773 has no LWM and little potential for recruitment. The banks in this area are near vertical and the riparian vegetation is composed exclusively of invasive species (mainly Himalayan blackberry).

Flow in the channel goes subsurface in the dry season approximately 15 feet downstream from the plunge pool that is formed by the McCleary Culvert. This location is 105 feet upstream of Culvert 990773 (see Figure 9). The loss of water indicates infiltration to an underlying aquifer. No springs or seeps were visible around the stream in August 2019, indicating the aquifer does not have a shallow water table. There was no indication of hyporheic flow, further indicating the water table is not shallow.

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the channel both vertically and laterally of the Unnamed Tributary of Mox Chehalis Creek.

2.7.1 Reference Reach Selection

The most appropriate reference reach for this project is the forested riparian reach immediately downstream of Culvert 990773 (Figure 13). The bed width and bed surface are similar to upstream of the McCleary Culvert and the reach downstream of the plunge pool created by the McCleary Culvert. This reference reach was chosen because it is stable and located where it receives all the water passing through Culvert 990773. It also avoids any possible remaining influence from installation of the McCleary Culvert. The measured bankfull width was 9.5 feet. The slope through this section is about 1.6%. The reference reach bankfull width measurement location corresponds to the bed surface characterization Site 2 on Figure 15. For bed surface conditions in this location, see Section 2.7.3.

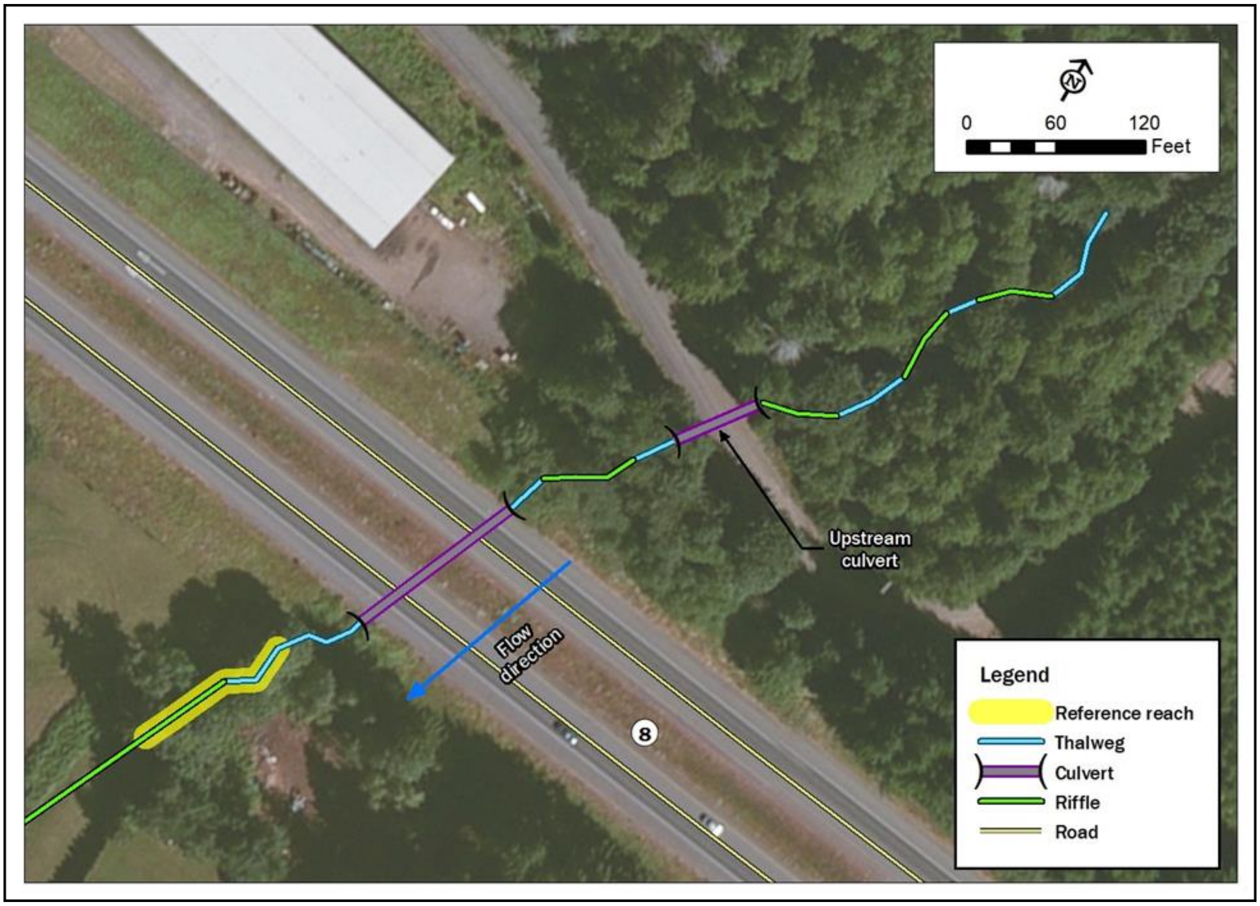

Figure 13: Reference reach for proposed design of Culvert 990773 replacement

2.7.2 Channel Geometry

A longitudinal profile of the thalweg of the unnamed stream in the project area is shown in Figure 14. Channel geometry was measured upstream and downstream of Culvert 990773 (Figure 15). The furthest upstream location was approximately 370 feet upstream of the McCleary Culvert where bankfull width was measured to be 8.1 feet while the channel top width was up to 13.3 feet in the wider pools. Between the McCleary Culvert and Culvert 990773, bankfull width was measured to be 10.6 feet. However, this measurement was in a reach that had to adjust to the erosion of fill placed upstream and to the redirection of a small ditch to join the main channel. The bankfull width was measured at the location where the ditch flows into the main channel, although it was dry at the time of the visit. Therefore, this measurement represents the widest channel geometry in the unnamed stream upstream of SR 8.

Two locations were chosen for bankfull width measurements in the reference reach downstream of Culvert 990773. The first location was where the unnamed stream passes through a natural riparian area; here the bankfull width was measured to be 9.5 feet. The second downstream location was where the unnamed stream passes through a modified reach between landscaped lawns with minimal riparian vegetation; here the bankfull width was measured to be 9.0 feet. The bankfull width used in the design was 9.5 feet as measured within the reference reach. See Table 3 and Figure 16 for a summary of bankfull width measurements.

The channel upstream of the McCleary Culvert is narrow and somewhat sinuous (Figure 17). The channel slope in this area averages 3.3 percent but is up to 6 percent in many locations (Figure 14). While there are areas of bank erosion, the channel appears to be stable, and the erosion is due to the natural processes balancing erosion and deposition in a sinuous reach.

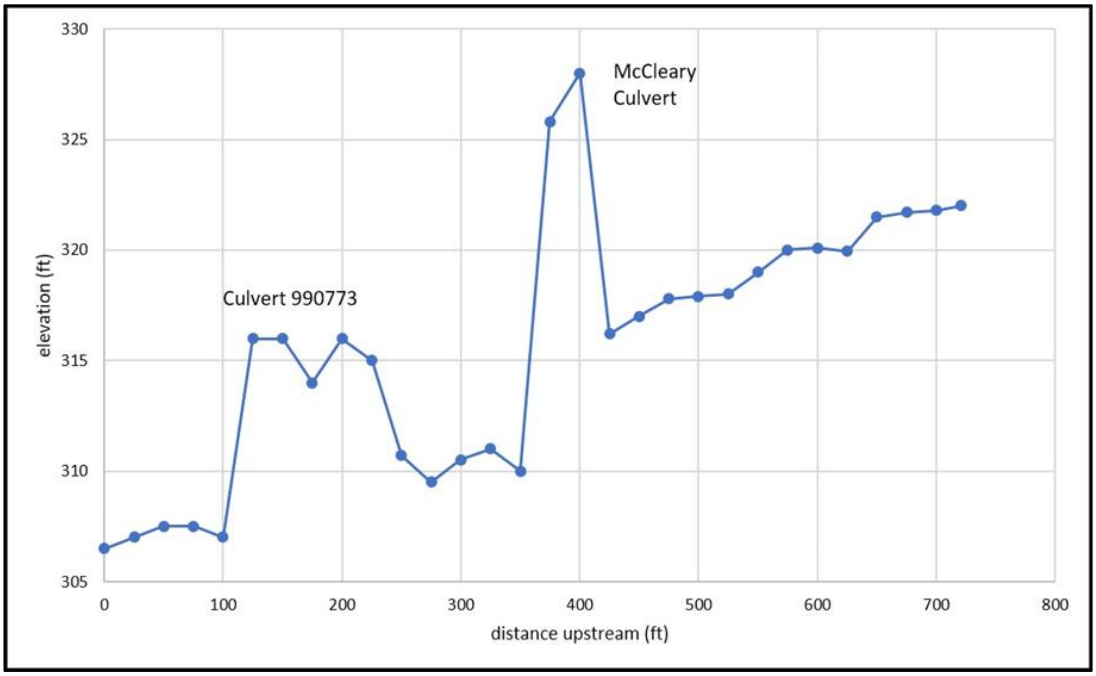

Figure 14: Thalweg profile of the Unnamed Tributary to Mox Chehalis Creek

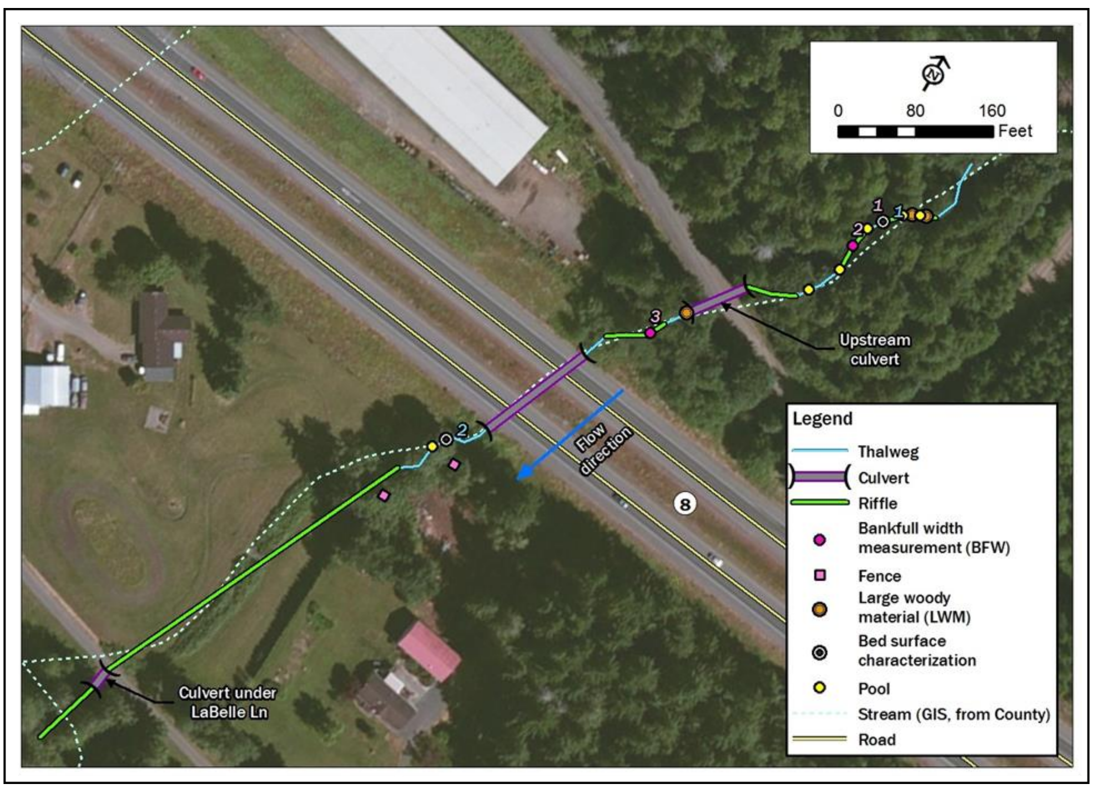

Figure 15: Detailed site map of the Unnamed Tributary to Mox Chehalis Creek around Culvert 990773

Table 3. Bankfull Width Measurements

BFW number	Width (ft)	Included in design average?	Location measured	Concurrence notes
1	9.5	yes	80 ft Downstream	n/a
2	8.1	no	470 ft Upstream	n/a
3	10.6	no	50 ft Upstream	n/a
4	9.0	no	120 ft Downstream	n/a
Design BFW	9.5			

n/a – this information was not recorded in the original PHD.

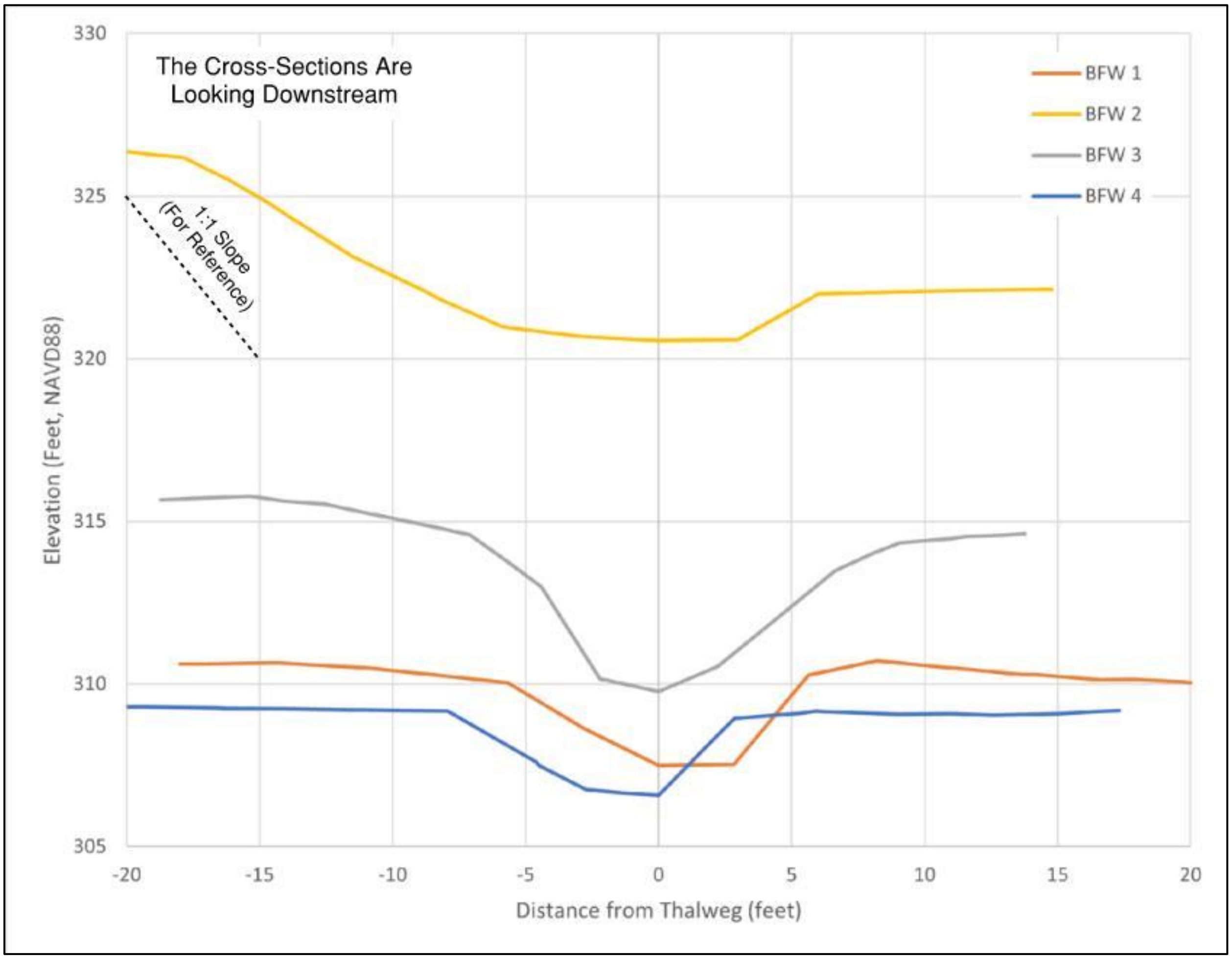

Figure 16. Existing Cross Section Examples

Figure 17: Stream channel upstream of McCleary Culvert

2.7.2.1 Floodplain Utilization Ratio

The 2013 WDFW Water Crossing Design Guidelines (WCDG) present two methodologies for designing a bridge crossing—confined bridge design and unconfined bridge design. The method to be used is determined by the Floodplain Utilization Ratio (FUR). The FUR is defined as the flood-prone width (FPW) divided by the bankfull width. The FPW is the water surface width at twice the bankfull depth, or the width at the 100-year flood. A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel.

The preliminary hydraulic design report showed that the FUR ranges from 1.7 to 2.1 and, therefore, the channel is confined. The specific measurements used to determine these values were not reported. For this final hydraulic design report, FUR values were revisited to verify this determination. The FUR was measured at six locations: three upstream of the McCleary

Culvert, two between the McCleary Culver and Culvert 990733, and in the reference reach (Figure 18). The results shown in Table 4 confirm the findings that this channel is confined. The reference reach is described as unconfined because it avoids any possible influence from the McCleary culvert (see Section 2.7.1).

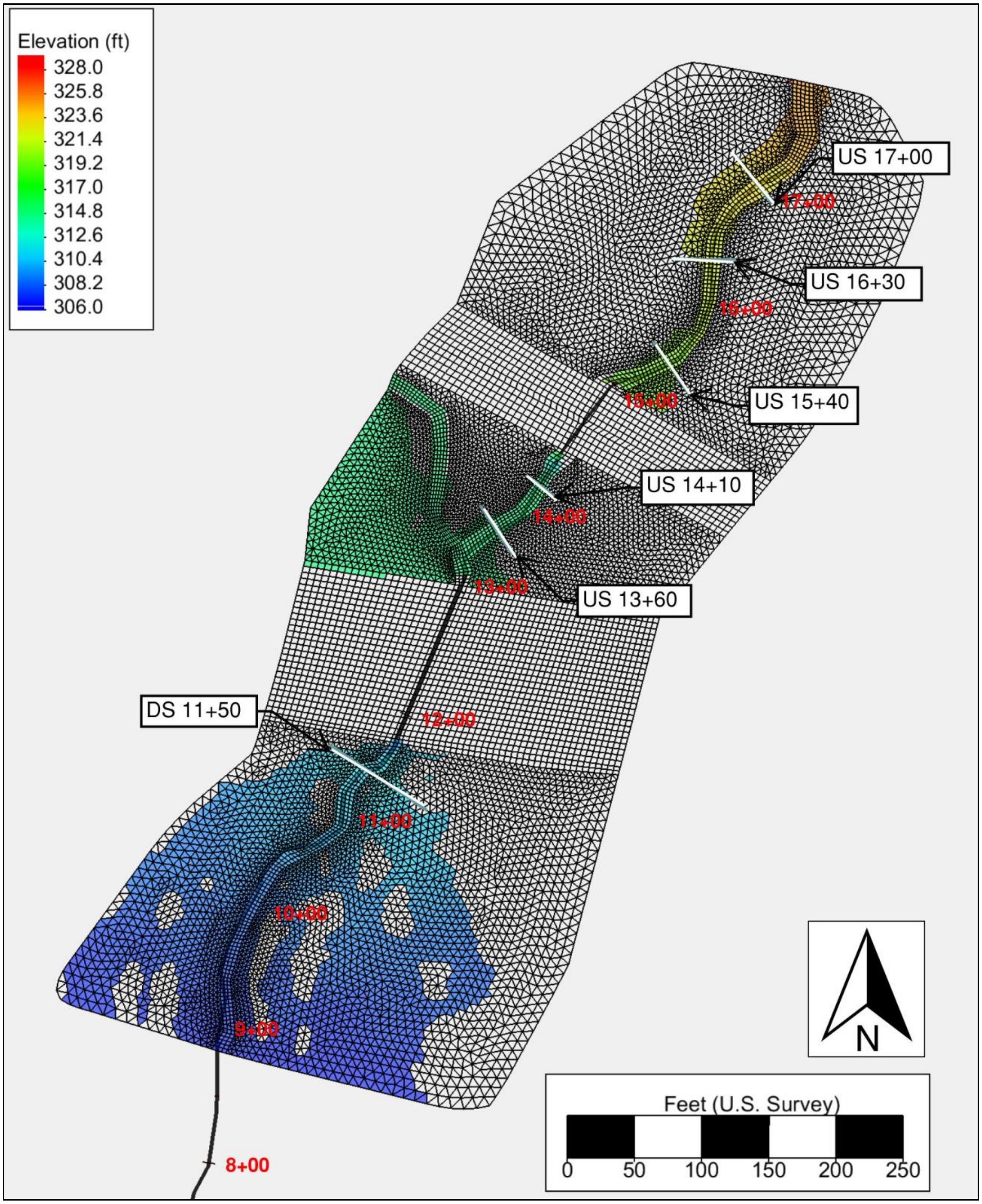

Figure 18: FUR locations

Table 4: FUR determination

Station	FPW (ft)	FUR	Confined/unconfined	Included in average FUR determination
DS 11+50	67.48	3.74	Unconfined	Yes
US 13+60	18.62	2.89	Confined	Yes
US 14+10	10.74	1.67	Confined	Yes
US 15+40	27.87	1.93	Confined	Yes
US 16+30	18.62	1.59	Confined	Yes
US 17+00	33.19	4.35	Unconfined	Yes
Average	**29.42**	**2.69**	**Confined**	

2.7.3 Sediment

The channel bed surface and structure were evaluated visually throughout the reaches upstream and downstream of SR 8 and in detail at two locations, as shown on Figure 15. The first location was 250 feet upstream of Culvert 990773, where it flows through a forested hillslope upstream of any influence from the McCleary Culvert. The bed surface at this location is strongly armored with approximately 3 percent sand on the surface but over 90 percent sand subsurface (Figure 19). The gravels are not arranged with any specific surface structure (Figure 20). The large gravels on the bed surface have moss on them in a few locations indicating that they are mobile only during extreme flows. The edges of the channel and areas of the bank are a clay hardpan. The median grain size of the bed surface at this location is 1.1 inches (Table 5).

The bed sediment was also measured 100 feet downstream of Culvert 990773 in the reference reach where it flows within a riparian area. The channel was dry at the time of the visit, and there was very little sand on the surface (Figure 21). The subsurface was examined and found to contain approximately 60 percent sand, showing the channel bed surface in this reach to be highly armored (Figure 22). There was no structure to the gravels on the bed surface. The median bed surface grain size was 1.5 inches (Table 5).

The channel bed maintained a similar gravel distribution between the upstream and downstream sites (Table 5).

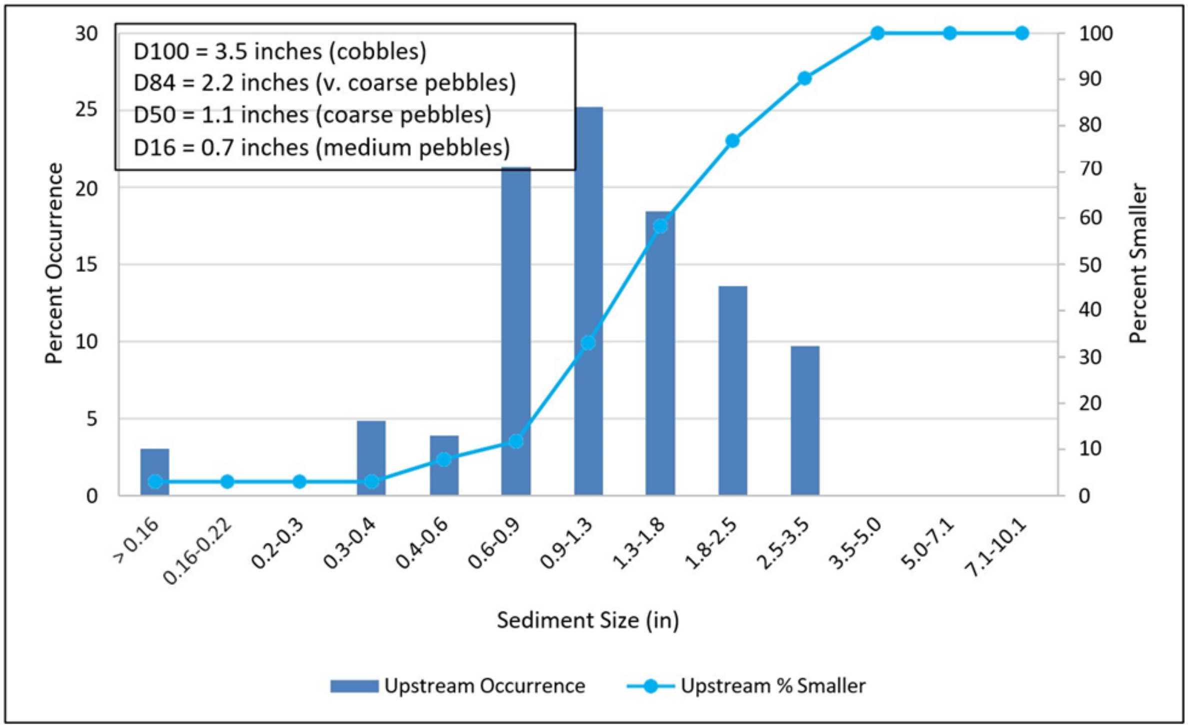

Figure 19: Upstream sediment size distribution

Figure 20: Stream channel where upstream bed surface characterized

Table 5: Sediment properties near the project crossing

Particle size	Upstream Pebble Count # diameter (in)	Downstream Pebble Count # diameter (in)	Average diameter for design (in)
Included in average?	Yes	Yes	
D_{16}	0.7	0.8	0.7
D_{50}	1.1	1.5	1.3
D_{84}	2.2	2.5	2.3
D_{100}	3.5	5.0	4.2

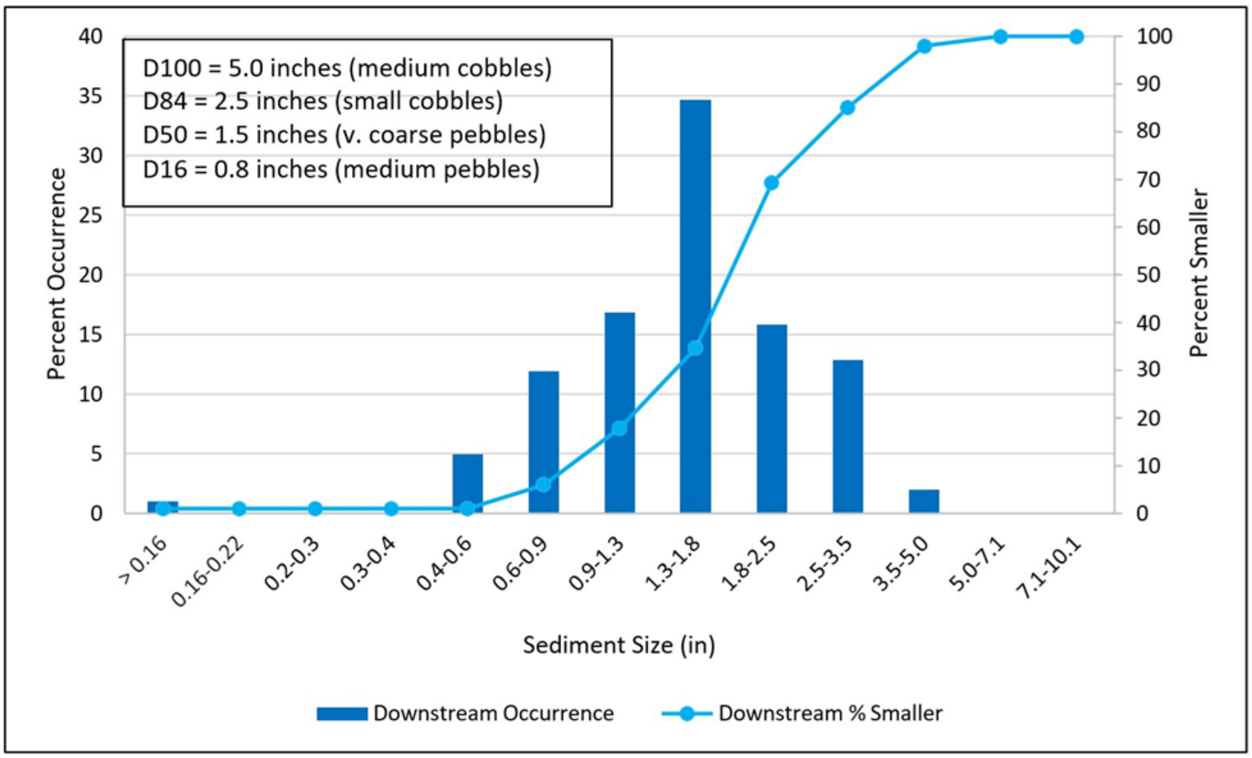

Figure 21: Downstream sediment size distribution

Figure 22: Channel bed location of downstream bed surface characterization

2.7.4 Vertical Channel Stability

Replacing Culvert 990773 is not expected to trigger a significant change in the channel bed profile through either erosion or deposition. The channel downstream of Culvert 990773 is stable. Upstream of Culvert 990773, there is a risk of major changes associated with the McCleary Culvert. The McCleary Culvert is creating a significant disconnect in the channel profile (Figure 23) that will adjust when the McCleary Culvert is either replaced or fails. When the McCleary Culvert is replaced, at some point in the future, by a managed construction project, the channel profile will regrade naturally over time causing aggradation within Culvert 990773. If the McCleary Culvert fails, there is a strong potential for rapid headcut erosion upstream of SR 8 as the channel erodes through the aggraded deposits upstream of McCleary Road and moves sediment downstream toward the SR 8 crossing. Rapid deposition of eroded sediment within Culvert 990773 would be expected followed by channel adjustment over time. The design of Culvert 990773 has taken this into account allowing additional vertical clearance for future channel aggradation. The proposed culvert width and height is sufficient that deposition resulting from removal of the upstream culvert will not impair culvert function. See Section 4 for more detail on the proposed channel and structure design.

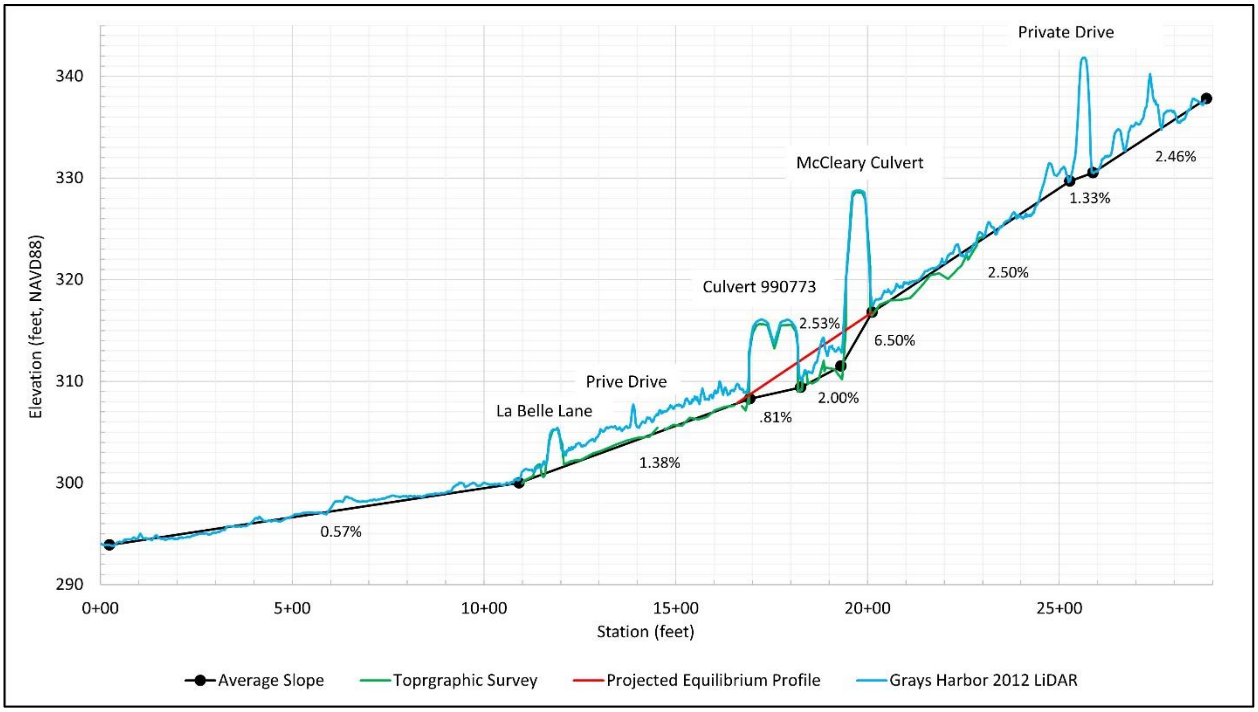

Figure 23: Longitudinal profile

2.7.5 Channel Migration

The watershed area upstream of Culvert 990773 is forested and relatively steep terrain. The slopes on either side of the unnamed tributary to Mox Chehalis Creek provide a v-shaped ravine, indicating a steep channel that does not laterally migrate. The greatest disturbance to the stream in this area is due to the placement of the McCleary Culvert. Installation of the McCleary Culvert led to major vertical channel adjustment but no lateral movement. There is minimal risk of channel migration upstream of Culvert 990773 beyond what is natural. LiDAR of the area illustrates drainage from area hillsides but does not show evidence of relict channel paths (Figure 24).

Downstream of Culvert 990773, where the unnamed tributary crosses the Mox Chehalis valley bottom, it is possible for Mox Chehalis Creek mainstem to migrate laterally. Migration of the Mox Chehalis Creek channel could lengthen or shorten the unnamed tributary stream length. Because the confluence is over 800 feet downstream of Culvert 990773, lateral channel migration of Mox Chehalis Creek is not expected to reach the location of the project.

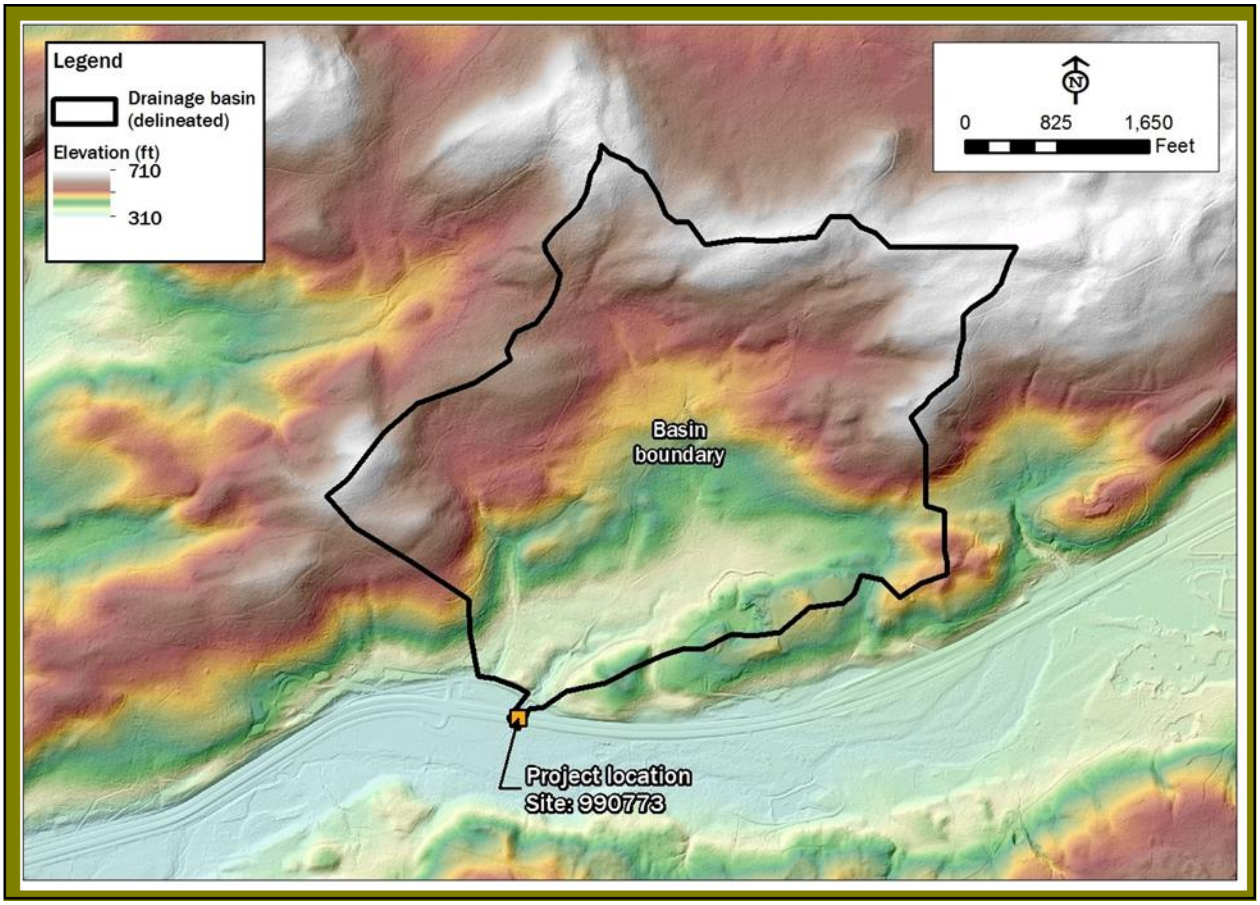

Figure 24: LiDAR of drainage basin associated with Culvert 990773

3 Hydrology and Peak Flow Estimates

WSDOT 2019 guidelines offer multiple methods by which the flows in a drainage basin may be calculated. Three of these methods rely on the USGS regression equations specific to the location. We applied the stream delineation from Grays Harbor County and combined it with field reconnaissance findings to define drainage basin boundaries and drainage area that accounted for the steep upstream and low gradient downstream topographies (see Figure 2).

We applied the Flood Q regression tool to determine flow rates at a range of mean recurrence intervals (Table 6). The specific rainfall region was determined from the map of regression regions in Washington State. The annual precipitation value used in the computations was based on the 30-year annual precipitation data for years 1981–2010 as re-sampled on a 30-meter cell size from the PRISM Climate Group. Mean annual precipitation is 90.0 inches over a drainage are of 0.606 square miles. All of Grays Harbor County, including the project location, is in the USGS regression region 4.

WSDOT recognizes climate resilience as a component of the integrity of its structures, and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 132 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 15.6 percent, yielding a projected 2080 100-year flow of 152.6 cfs.

Table 6: Peak flows for Unnamed Tributary to Mox Chehalis Creek at SR 8

Mean recurrence interval (MRI) (years)	USGS regression equation (Region 4) (cfs)
2	64.5
10	81.5
25	101
50	116
100	132
500	167
Projected 2080 100	152.6

4 Water Crossing Design

This section describes the water crossing design developed for the SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for the Unnamed Tributary to Mox Chehalis Creek at SR 8 MP 9.10.

The 2013 WCDG presents two scenarios where a stream simulation design can be employed. The proposed culvert meets all attributes of the first scenario, which is applicable when channel slopes are less than 4 percent.

4.1.1 Channel Planform and Shape

The WCDG requires that the channel planform and shape mimic conditions within a reference reach. The reach downstream of the culvert was determined to be a good reference reach as described in Section 2.7.1. To match planform, a slight skew angle of 15 degrees was assumed for the channel alignment through the proposed culvert.

In general, the channel design replicates the downstream reference reach geometry with some added structures to let the channel naturally adjust over time to form habitat complexity. The downstream reference reach is less confined than upstream reaches, so using the WCDG guidance results in a slightly wider channel than in other reaches. The proposed channel section is provided in Figure 25. Figure 26 compares the proposed cross section to cross-sections upstream of SR 8 and in the downstream reference reach at Station 10+70. Several factors were assumed in developing the channel design.

The general channel cross sectional shape will include a channel base equal to the downstream BFW (9.5 feet). A simplified 10:1 cross-slope will be included in the channel base to provide an initial thalweg. The thalweg will naturally adjust soon after construction based on hydraulic interaction with the boulders and sediment delivery. 2H:1V side slopes from channel base up to the culvert wall to match the bankfull depth of the reference reach. Because the channel design is based on the adjacent reference reach, the stream is continuous and is expected to perform similarly to adjacent reaches.

A low flow channel will be graded during construction to connect habitat features together and ensure that the project does not create a low flow barrier. The low flow channel location will be directed by the Engineer in the field during construction.

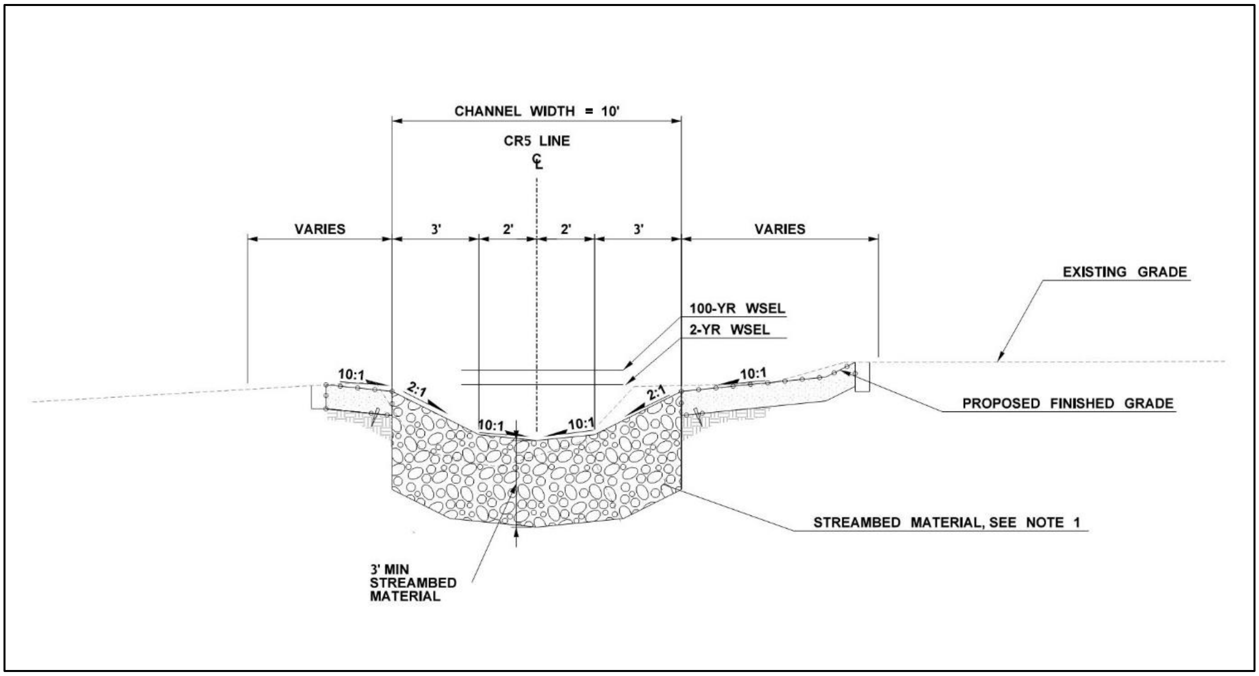

Figure 25: Design cross section

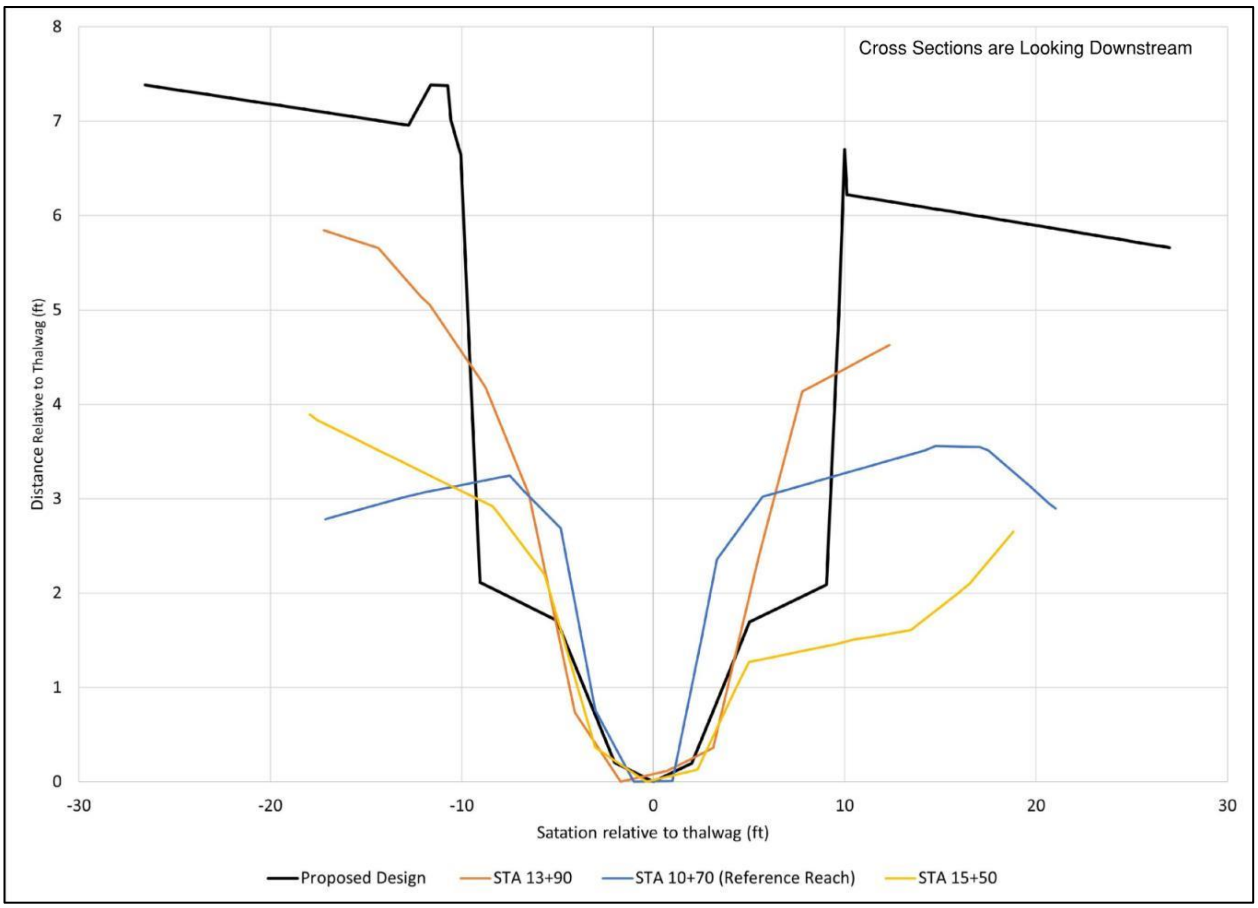

Figure 26: Proposed Cross Section Superimposed with existing survey cross section

4.1.2 Channel Alignment

The Unnamed Tributary to Mox Chehalis Creek will be realigned 37 feet west of the existing location. The existing channel alignment indicates that the channel was previous realigned when the existing culvert was constructed. The proposed realignment will facilitate construction by allowing the existing channel to remain during construction thereby reducing the need for stream diversion. The proposed alignment will maintain the existing 15 degree skew relative to SR 8. The length of the stream grading is 295 feet. The upstream tie-in point is 106 feet from the new culvert inlet and the downstream tie-in point is 59 feet from the new culvert outlet.

4.1.3 Channel Gradient

The WCDG recommends that the proposed culvert bed gradient not be more than 25 percent steeper than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). Because the upstream slope has been altered by the McCleary Culvert the design slope for the streambed was matched to the downstream slope. This comparison produces a gradient ratio through the new culvert of 1.2 percent for post-construction conditions. The constructed channel slope will be 1.3 percent between the tie-in points.

As discussed in Section 2.7.4, it is anticipated that when the McCleary culvert is replaced, or if it fails, aggradation will occur through the SR 8 culvert. The height of the proposed culvert will be elevated to accommodate this future aggradation so that the minimum required freeboard will be maintained through the life of the structure. If and when this aggradation occurs, the channel gradient is expected to increase up to 2.1 percent at most. At this slope, the sediment depth at the culvert inlet will have increased 2 feet.

If the McCleary Culvert is replaced in a controlled manner, sediment delivery and aggradation at the SR 8 crossing is likely to occur gradually over time until a new equilibrium is reached. If, however, the McCleary Culvert fails, or McCleary Road is decommissioned and the culvert simply removed, rapid aggradation could occur immediately upon mobilization of the newly released sediment. Regardless of the rate of sediment accumulation, the channel would achieve a new equilibrium over time at roughly the same gradient.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 27 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard, and maintenance clearance terminology.

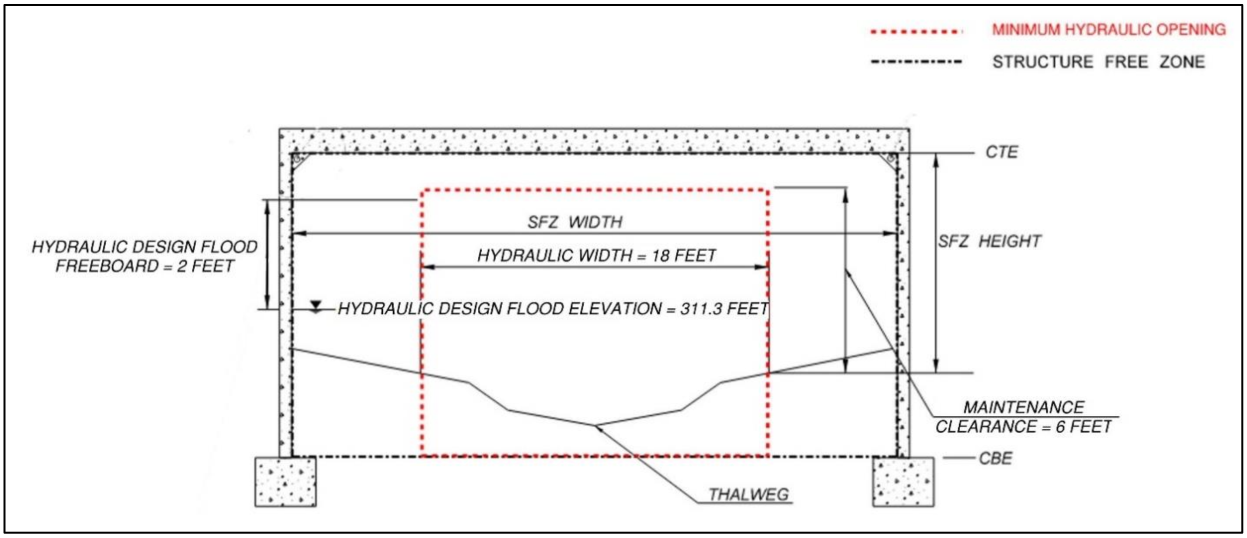

Figure 27: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing because the channel is confined with a FUR less than 3.0 and a bankfull width less than 10 feet *(refer to Section 2.7.2.1).*

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 18 feet was determined to be the minimum starting point.

The WCDG stream simulation methodology recommends sizing the span of the proposed structure based on the agreed upon bankfull width, with the span being 1.2 x bankfull width + 2 feet (WCDG Equation 3.2). Using this equation, along with the measured bankfull width of 9.5 feet in the reference reach discussed in Section 2.7, results in a structure span of 13.4 feet, rounded up to 14 feet for design purposes.

Initial modeling for a 14-foot span culvert met the velocity ratio criteria with an upstream velocity of 6.78 ft/s and a decrease to 5.96 ft/s inside the culvert (velocity ratio of 0.88). However, the water surface profile, drop in velocity at the outlet, and variable velocity distribution upstream associated with the secondary drainage channel confluence suggested a slight flow acceleration in a 14-foot span culvert that could be influenced by the upstream culvert at McCleary Road.

To assess an appropriate hydraulic width that would be “forward compatible” if the McCleary Culvert is removed or fails in the future, additional modeling was performed for an 18-foot culvert assuming the McCleary Culvert is removed, and the stream channel is graded for a smooth profile through that culvert area. The analysis showed that a minimum hydraulic width of 18 feet is necessary to allow for natural processes to occur under current flow conditions and under conditions when the McCleary Culvert is replaced.

The 18-foot hydraulic width was also analyzed under projected 2080 100-year flow conditions. Table 7 compares the velocities of the 100-year and projected 2080 100-year events. A review of the full channel length indicates the structure velocities are within the full range of the open channel velocities (see Section 5.4 for more detail). Table 7 also shows that velocities throughout the channel will increase as future flows increase, however, the velocity through the structure remains within the range of open channel velocities even under 2080 flow conditions.

Based on the factors described above, a minimum hydraulic width of 18 feet was determined to be necessary to allow for natural processes to occur under current and future flow conditions.

Table 7: Velocity comparison for 18-foot structure

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
Downstream of structure (STA 10+00)	4.06	4.17
Reference reach (STA 10+70)	1.66	1.73
Downstream of structure (STA 11+05)	1.77	1.91
Through structure (STA 12+28)	3.88	4.12
Upstream of structure (STA 14+05)	4.73	5.36

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 8.

The minimum required freeboard at the project location, based on bankfull width, is 2 feet above the 100-year water surface elevation (WSE) (Barnard et al. 2013, WSDOT 2022a).

Anticipated long term aggregation and debris risk, as described in Section 2.7.4, were included in the consideration of vertical clearance at this crossing. When the McCleary culvert is replaced, it is estimated that up to an additional two feet of aggradation could occur at the inlet of the new SR 8 culvert. The water surface elevations shown in Table 8 assume the existing McCleary culvert has been removed and the anticipated aggradation has occurred.

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by 0.1 feet for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or large woody material (LWM). If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 include meander bars and LWM habitat features within the structure that may need to be maintained. However, the boulders used in the meander bars are sized so that they will be immobile up to the 100-year event and, therefore, are not expected to require maintenance. In addition, SR 8 is already being raised several feet to accommodate the new structure so additional maintenance clearance is impractical. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width.

Table 8: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	11+61	12+97
Thalweg elevation (ft)	308.1	309.9
Highest streambed ground elevation within hydraulic width (ft)	310.2	312.0
100-year WSE (ft) **no McCleary Culvert**	311.3	312.8
2080 100-year WSE (ft) **no McCleary Culvert**	311.4	312.9
Required freeboard (ft)	2	2
Recommended/Required maintenance clearance (ft)	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	313.3	314.8
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	313.4	314.9
Recommended/Required minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	316.2	318.0
Required minimum low chord (ft)	313.4	314.9
Recommended minimum low chord (ft)	316.2	318.0
Design Low Chord (ft)	314.2	316.0

4.2.3.1 Past Maintenance Records

WSDOT Olympic region maintenance records were unavailable.

4.2.3.2 Wood and Sediment Supply

The stream may be able to transport a log that is approximately 1.0 feet DBH at 10 feet long based on the anticipated flow depths and a channel width of 9.5 feet. The channel does not have the stream power to move larger woody material that could otherwise be an issue for an 18-foot-wide opening, and thus additional freeboard for LWM is not required.

Currently, the upstream sediment supply is restricted by the McCleary Culvert. When the McCleary Culvert is replaced, sediment movement will increase through the SR 8 culvert and aggradation is anticipated. This aggradation is accounted for in the vertical clearance of the designed structure.

4.2.3.3 Impacts

This crossing meets freeboard requirements, so no substantial impacts are expected.

4.2.3.4 Impacts to Fish Life and Habitat

Based on currently available information, the proposed freeboard will result in no substantial impacts to fish life and habitat.

4.2.4 Hydraulic Length

A minimum hydraulic width of 18 feet is recommended up to a maximum hydraulic length of 180 feet. If the hydraulic length is increased beyond 180 feet, the hydraulic width and vertical clearance will need to be reevaluated. The designed structure length is 135 feet, which is well below the maximum length for this hydraulic opening.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 8 through this corridor.

4.2.6 Structure Type

A concrete box culvert is recommended by WSDOT HQ Hydraulics for the proposed crossing. The proposed structure was evaluated hydraulically and found to eliminate existing backwater. It also allows the velocity through the structure to be similar to the open water velocities. In addition, the box structure allows for the lowest raise in road height.

4.3 Streambed Design

This section describes the streambed design developed for the Unnamed Tributary of Mox Chehalis Creek at SR 8 MP 9.10. Plan sheets and details of the streambed design are provided in Appendix D

4.3.1 Bed Material

The recommended streambed material gradation is based on bed composition in the reference reach, downstream of the project site. Bed material in the reference reach is characteristic of the bed material throughout the reach including upstream of the McCleary Culvert where the channel is also in a stable and natural condition. The reference reach has a 1.6 percent slope, which is similar to the 1.3 percent slope of the proposed crossing. The channel bed is heavily armored in the reference reach, indicating low mobility of the largest portion of the sediment size distribution. Table 9 shows the streambed material gradation from pebble counts conducted during field reconnaissance.

The proposed streambed material will be a mix of 60 percent 4-inch streambed cobbles and 40 percent streambed sediment per WSDOT specifications 9-03.11(2) and 9-03.11(1) respectively. Table 9 shows that this mix matches closely to the existing channel material. This mixture will provide fish with adequate sediment for spawning. The channel will only provide access for the fish seasonally because the downstream channel becomes dry during summer months.

Streambed stability calculations indicate that the proposed bed material will be highly mobile during flows as high as the 25-year event or greater. To help stabilize the bed during high flows, meander bars will be constructed inside the new culvert. Meander bar material was determined using the latest WSDOT developed design that consists of a structure head comprised of one-man boulders and a coarse cobble structure tail. The coarse cobble will consist of 70 percent 10-inch streambed cobbles (9-03.11(2)) and 30 percent streambed sediment (9-03.11(1)). During construction, addition fines will be washed in as needed to seal the bed. These meander bars will also help create the complexity that occurs naturally where banks are of variable width.

Supply of large gravels to the proposed culvert will be infrequent until the McCleary culvert is replaced. The added meander bars will have an additional benefit of maintaining a condition of partial mobility of the gravels and sands that are transported to and through the proposed culvert by creating a variable bed surface with locations for smaller material to deposit.

Table 9: Comparison of observed and proposed streambed material

Sediment size	Observed diameter for design (in)	Streambed Material Mix diameter (in)	Meander Bar Material Mix diameter (in)
$\mathbf{D_{16}}$	0.7	0.3	0.6
$\mathbf{D_{50}}$	1.3	1.4	2.4
$\mathbf{D_{84}}$	2.3	2.8	7.6
$\mathbf{D_{95}}$	3.5	3.5	9.5
$\mathbf{D_{100}}$	4.2	4.0	10.0

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for the Unnamed Tributary of Mox Chehalis Creek at SR 8 MP 9.10.

4.3.2.1 Design Concept

The new culvert will be 135 feet long, and only 18 feet wide, so channel complexity within the culvert is in the design to prevent a flat, plane-bed, shallow flow condition from developing over time. In leu of LWM placed inside the culvert, meander bars are recommended to provide complexity within the culvert. Meander bars will be strategically placed in the stream banks within the culvert 32 feet apart on alternating sides. Four meander bars will be placed inside the culvert. The meander bars will be incorporated into the 2:1 side slopes to help retain the side slopes and minimize the potential for the stream thalweg to entrench along a culvert side wall.

To provide additional fish habitat, the existing channel downstream of the proposed crossing will be retained to provide side-channel habitat. See Section 4.1.2 for discussion of the proposed channel realignment.

The suggested targets for LWM quantities presented in "A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State" (Fox and Bolton 2007) provide the basis for determining the amount of wood placed within the constructed channel. Calculations in WSDOT's wood quantity calculation spreadsheet depend upon the total length of reconstructed channel, including reaches internal to structures, and the BFW of the stream channel. All relevant calculations are included in Appendix F.

For a BFW of 10 feet, the minimum key piece of density is 3.35 key pieces per 100 feet. With 295 feet of regrading proposed at this site, the LWM targets are 10 key pieces, 34 total pieces, and a volume of 116.5 cubic yards.

To satisfy the large volume target, the proposed design incorporates buried logs. By burying some pieces, logs can be stacked vertically. This allows a larger volume of wood to fit within the regraded channel and still have most logs engaged within the channel's low flow area. The buried wood also provides anchoring for other pieces by lashing logs together. Buried logs will also take longer to decompose than surface logs so they will remain in the system longer.

The proposed design, shown in Figure 28 and Appendix D, incorporates 32 key pieces and 50 total pieces of LWM, which exceed the targets. A volume of 124.4 cubic yards is proposed, which exceeds the recommended volume. To ensure the constructability of the LWM design, four cluster types are proposed, as seen in Appendix D. The different clusters provide variability in habitat enhancement and aesthetics while providing clear plans for the contractor.

LWM should not cause problems at the inlet of the culvert because the channel does not have the capacity to transport significate sized wood. Buoyancy calculations were also conducted to ensure the wood would not be mobilized. Any wood that is being transported downstream from the upstream reach will most likely not pass the inlet of the McCleary Culvert or rack on the wood before the culvert.

The LWM being placed will most likely be used for non-natal rearing seasonally. Coho Salmon, steelhead, coastal cutthroat, and resident trout can use it during the fall and winter when flow is present.

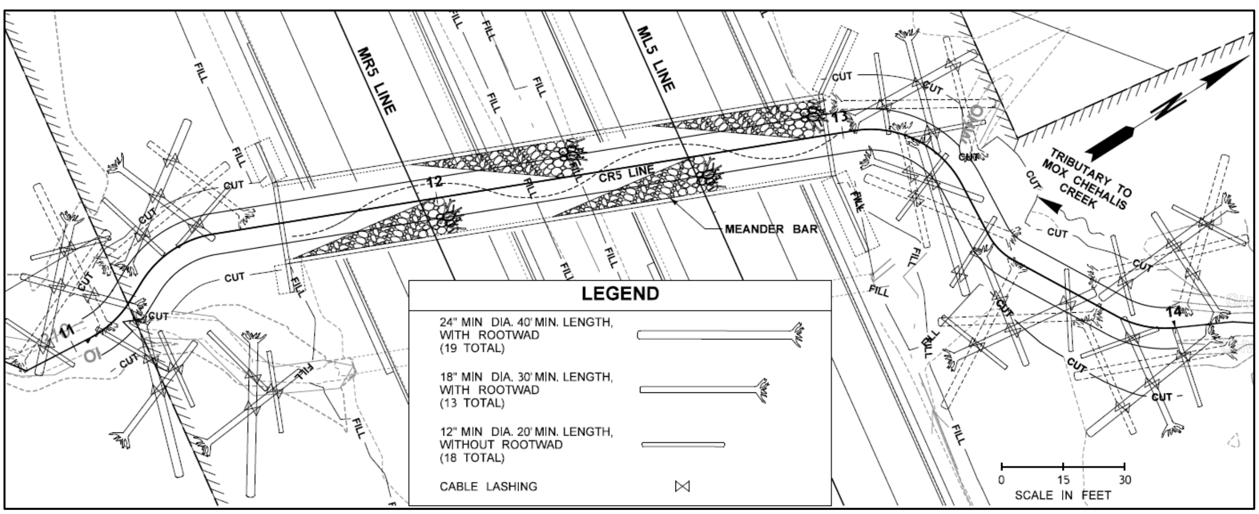

Figure 28: Layout of habitat complexity

4.3.2.2 Stability Analysis

For simple multi-log structures, large woody material stability analysis is typically completed using the USFS-supplied *Computational Design Tool for Evaluating the Stability of Large Wood Structures* spreadsheet calculator (Rafferty 2016). The interactions between logs are normally entered into the spreadsheet to determine the stability of each individual log in a structure. However, due to the complexity of the log interactions in the proposed clusters at this crossing, determining the individual stability of logs in a cluster was not feasible. Instead, the stability of the log cluster as a whole was determined. To do so, the USFS-supplied calculation spreadsheet was used to determine the vertical and horizontal forces acting on each individual log, without accounting for interactions between logs. The forces occurring on individual logs were then summed to determine the total force occurring on the entire log cluster. This is a valid approach because all logs in a cluster are lashed together, and therefore forces on a given log act on the whole cluster.

The stability analysis was completed using the hydraulic modelling results from the 100-year flood. All calculations are included in Appendix F, and a summary of the stability of individual logs and entire clusters is shown in

Table 10. The USFS-supplied tool's assumptions include:

- Flows are not highly turbulent
- Stable and uniform stream geometry
- No debris flows
- Relatively low energy stream that transports sediment smaller than cobbles
- Simple log geometry (e.g., no branches, no partial rootwads)

Because the flow in the unnamed tributary is relatively low, even during a 100-year event, and the proposed logs are so large, the calculation spreadsheet was unable to calculate the horizontal forces for some logs. This occurs when the cross-sectional area of the log is greater than the wetted area of the stream, which leads to an imaginary result in one of the program's internal calculations. The design team has made the assumption that if the cross-sectional area of the logs is greater than the wetted area, then the water will not have sufficient force to move a log of that size. The pieces of LWM that experience this problem have the horizontal force balance marked with an "N/A" in

Table 10.

For clusters A, B, and C, the horizontal forces of the logs with “N/A” horizontal force balances were not included in the cluster total horizontal force balance as other logs supplied sufficient horizontal ballast to stabilize the cluster. In cluster D, however, the horizontal forces were unable to be calculated for both ballasting logs. So, the design team extended the assumption that a log with an “N/A” horizontal force balance was stable and assumed that logs 1 and 2 in cluster D would provide sufficient horizontal ballast to stabilize the cluster.

The LWM placed in this channel will not require anchoring.

Table 10: Summary of log ballast requirements

Cluster Type	Log (ID number)	Diameter (in)	Length (ft)	Vertical Force Balance (lbf)	Horizontal Force Balance (lbf)	Anchor requirements	
						Required ballast	Number of rock collars (three-man)
A	1	18	30	-914	125	N/A	N/A
	2	24	40	-2,572	-141	N/A	N/A
	3	24	40	-9,548	-40,731	N/A	N/A
	4	24	40	-19,777	-73,694	N/A	N/A
	5	12	20	-527	-457	N/A	N/A
	6	12	20	297	330	N/A	N/A
	Cluster Total	-	-	-11,435	-40,873	-	-
B	1	18	30	-1,332	-863	N/A	N/A
	2	24	40	-3,987	N/A	N/A	N/A
	3	18	30	-1,216	-7,870	N/A	N/A
	4	24	40	-15,582	-59,702	N/A	N/A
	5	12	20	438	41	N/A	N/A
	6	12	20	262	70	N/A	N/A
	Cluster Total	-	-	-5,833	-8,622	-	-
C	1	24	40	-4,218	N/A	N/A	N/A
	2	18	30	-239	204	N/A	N/A
	3	18	30	-395	-5,438	N/A	N/A
	4	24	40	-13,665	-53,381	N/A	N/A
	5	12	20	28	215	N/A	N/A
	6	12	20	-153	27	N/A	N/A
	Cluster Total	-	-	-4,976	-4,991	-	-
D	1	24	40	-3,953	N/A	N/A	N/A
	2	18	30	-1,460	N/A	N/A	N/A
	3	12	20	89	118	N/A	N/A
	4	12	20	368	20	N/A	N/A
	Cluster Total	-	-	-3,496	N/A	-	-

a. Assumes boulders with submerged specific gravity of 1.65.
b. Negative value indicates anchor and overburden moments exceed buoyant moments.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 8 Unnamed Tributary to Mox Chehalis Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.2.4 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.14 (Aquaveo 2021).

Three scenarios were analyzed for determining stream characteristics for the Unnamed Tributary to Mox Chehalis Creek with the SRH-2D models:

1) Existing conditions with the existing 4-foot-wide concrete box culvert under SR 8

2) Proposed conditions with a proposed 18-foot-wide culvert under SR 8

3) Future conditions with a proposed 18-foot-wide culvert under SR 8 and upstream restoration to remove the McCleary Culvert

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by David Evans and Associates (DEA) in July 2019. The survey data were supplemented with light detection and ranging (LiDAR) data (WSDNR, 2012). To combine the LiDAR data with the Survey data the LiDAR had to be resampled and point density had to be decreased to 10 ft cells. This did not affect the model. Proposed channel geometry was developed from the design grading surface created by DEA. All survey and LiDAR information is referenced against the NAVD88 vertical datum.

5.1.2 Model Extent and Computational Mesh

The model extends approximately 470 feet upstream of the upstream inlet of Culvert 990773 and 250 feet downstream of the outlet of Culvert 990773, to the confluence with Mox Chehalis Creek. The mesh boundaries are far enough away to not influence the hydraulics at the culvert.

The existing conditions model (Figure 29) includes two culverts, the SR 8 culvert and the McCleary culvert, and has 11732 nodes and 19488 elements. The proposed conditions model (Figure 30) retains the McCleary culvert and modifies the SR 8 culvert to match the proposed 18-foot box culvert, which is modeled as an open cut through the highway. The proposed conditions mesh has 11936 nodes and 18779 elements. The future conditions model retains the proposed SR 8 culvert but widens the McCleary crossing to 30 feet without a specific structure type (Figure 31). The future conditions mesh has 11937 nodes and 18761 elements. Patches were used along the roadway and for the stream channels for all three models. Paving was used for the rest of the mesh areas.

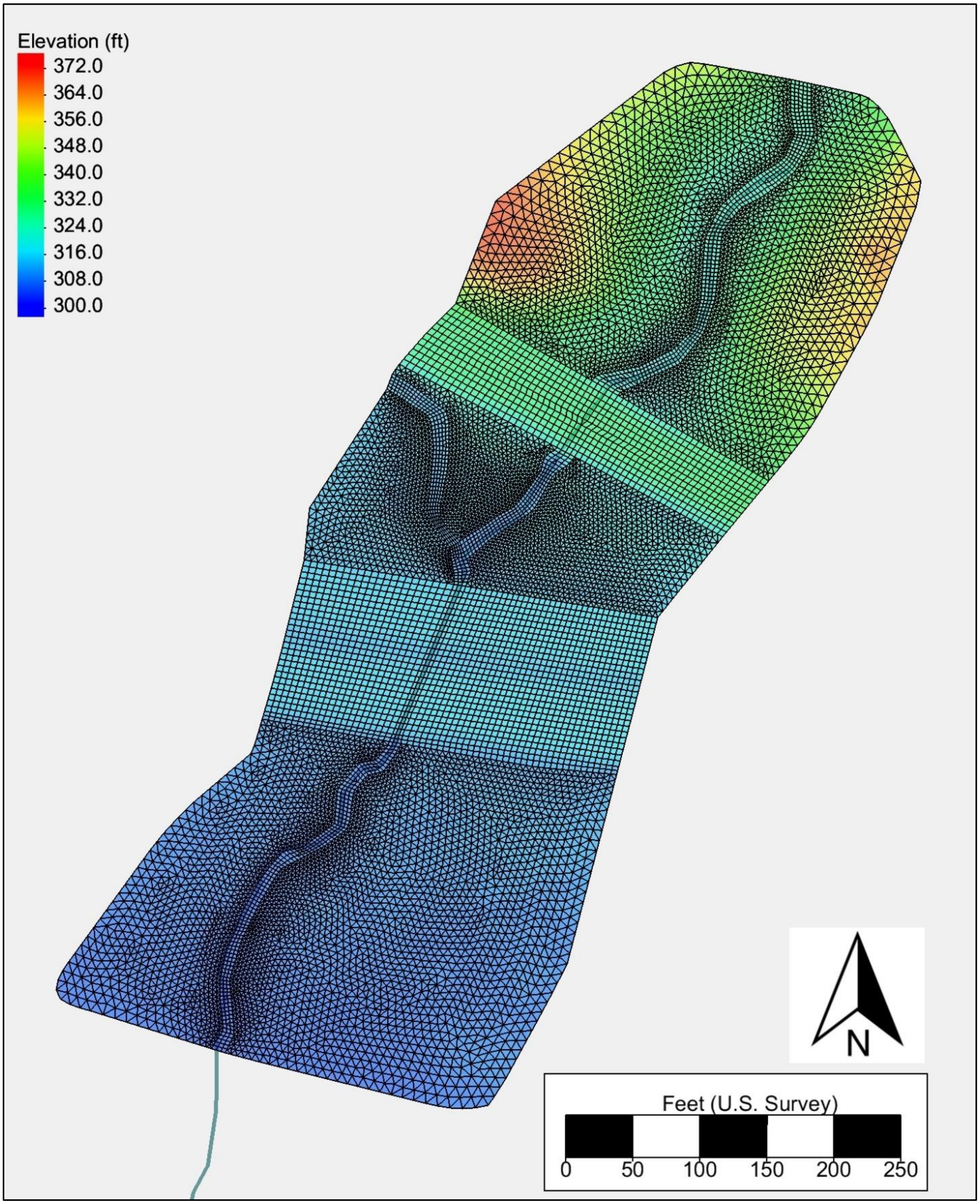

Figure 29: Existing conditions computational mesh with underlying terrain

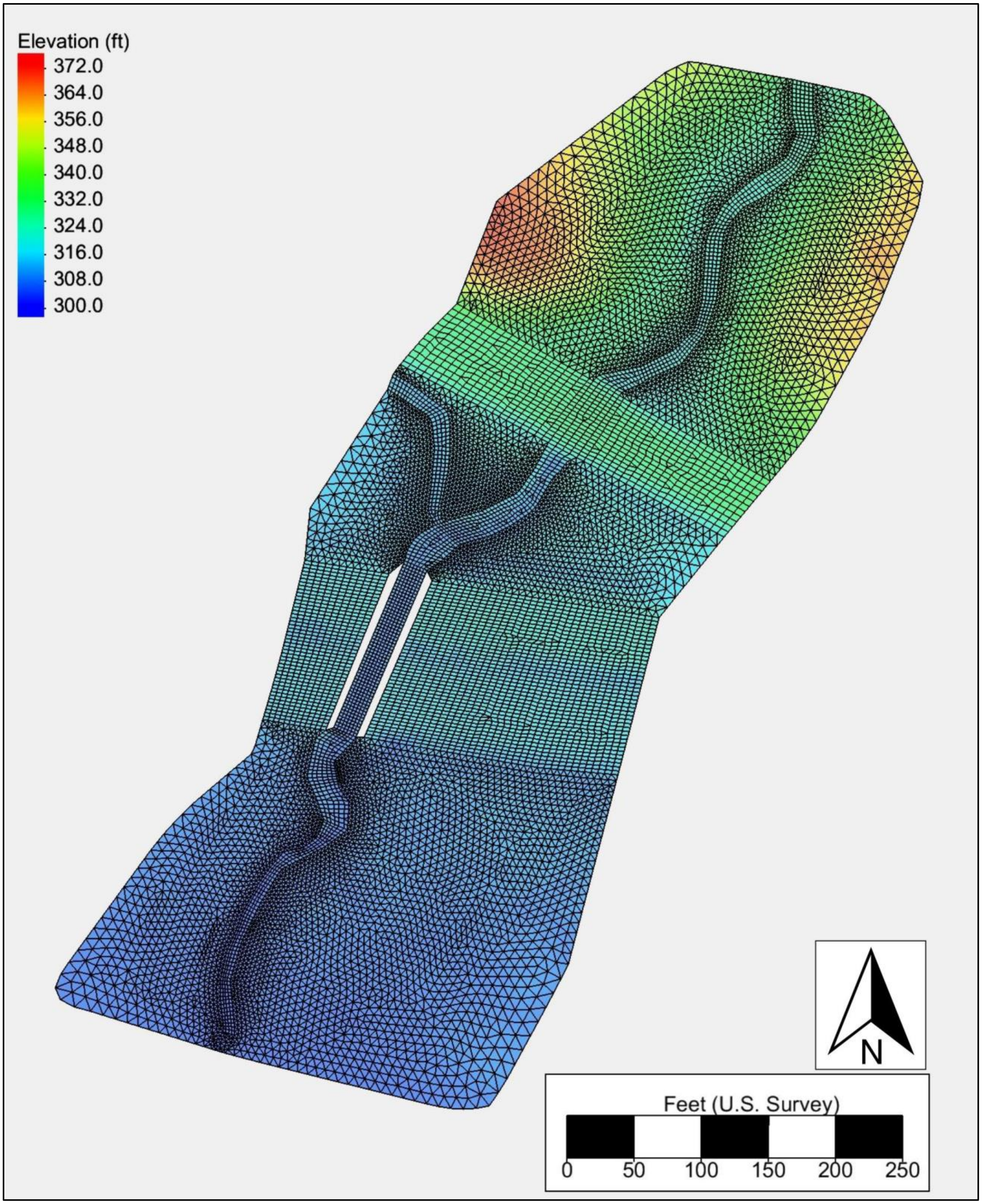

Figure 30: Proposed conditions computational mesh with underlying terrain

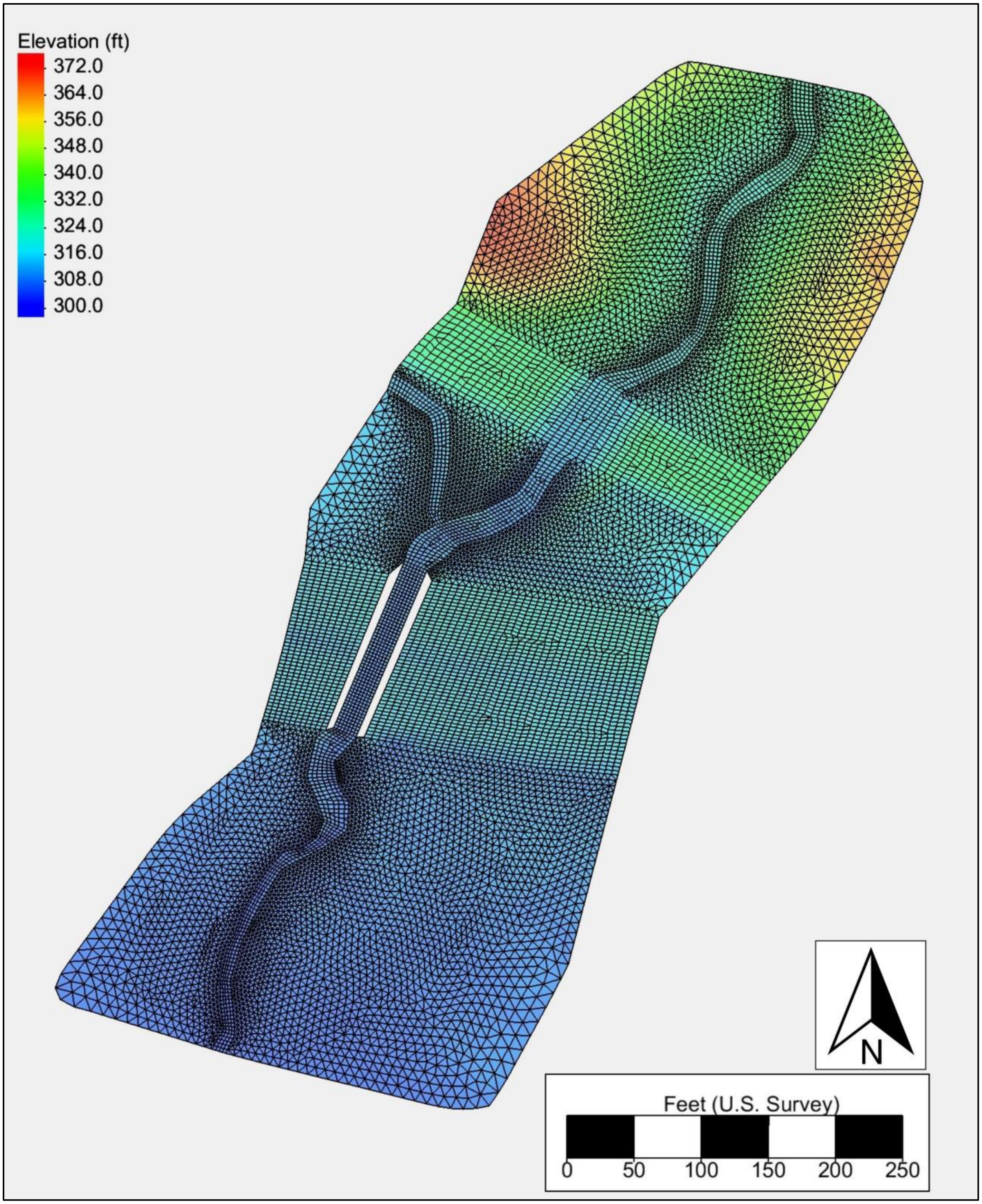

Figure 31: Future conditions computational mesh without The McCleary Culvert with underlying terrain

5.1.3 Materials/Roughness

The Manning's "n" values used in the existing model shown below in Table 11 are based on the WSDOT Hydraulics Manual (WSDOT 2022a) to represent the creek channel, roads, fields, and vegetated floodplain.

Manning's n values were set at the same values in the existing conditions (Figure 32) and proposed conditions (Figure 33 and Figure 34) models with one exception. Both proposed conditions models incorporate additional roughness upstream and downstream of the SR 8 culvert for LWM that will be placed during construction.

Upstream and downstream channels were assigned different Manning's n due to upstream having a moderate gradient and a low downstream gradient.

Table 11: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Upstream Channel	0.04
Downstream Channel	0.03
Paved Road	0.012
Forest	0.08
Lawn	0.035
LWM	0.08

Figure 32: Spatial distribution of existing conditions roughness values in SRH-2D model

Figure 33: Spatial distribution of proposed conditions roughness values in SRH-2D model

Figure 34: Spatial distribution of future conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

There are two upstream boundary conditions, one for the Unnamed Tributary to Mox Chehalis main channel at the north end of the mesh and one for a side channel that comes in from the west downstream of the McCleary culvert. The flow inputs described in Section 3 were divided so that about 11 percent of the total flow enters at the side channel. The inlet boundary conditions are the same for the three modeling scenarios as shown in Figure 35, Figure 36, and Figure 37. The 2080 predicted 100-year was only modeled for the proposed conditions models.

The inflow boundaries were modeled using a time series that increases the flow gradually to peak flow to improve model stability. The inflow time series for the main channel flow is shown in Figure 38, and the inflow time series for the side channel is shown in Figure 39. All the models started with a flow of 5 feet per second and was increased at one hour time intervals for four hours. The simulation was then run for an additional 6 hours at the peak flow value to ensure steady state was reached.

The downstream boundary was located approximately 300 feet downstream of the SR 8 culvert (990773) which was far enough downstream to not influence the hydraulics at the culvert. The exit conditions were model with a normal depth constant water surface elevation that was generated with a composite Manning's n of 0.06 and a slope of 0.013 feet. This boundary spans the bottom of the mesh to capture flooding in the area.

Additional boundary conditions were used to integrate the one-dimensional HY-8 model (Federal Highway Administration [FHWA] version 7.6) into the 2D mesh to model culverts. The existing model includes two culverts: the SR 8 culvert (990773) and the McCleary Culvert. Both culverts were modeled as 4-foot by 4-foot box culverts. The HY-8 input for the SR 8 culvert is shown in Figure 40 and the input for the McCleary culvert is shown in Figure 41. The proposed conditions model retains the McCleary culvert and the associated HY-8 boundary conditions. The future conditions model does not include these boundary conditions because both the SR 8 and McCleary crossings are modeled as open cuts through the road prisms.

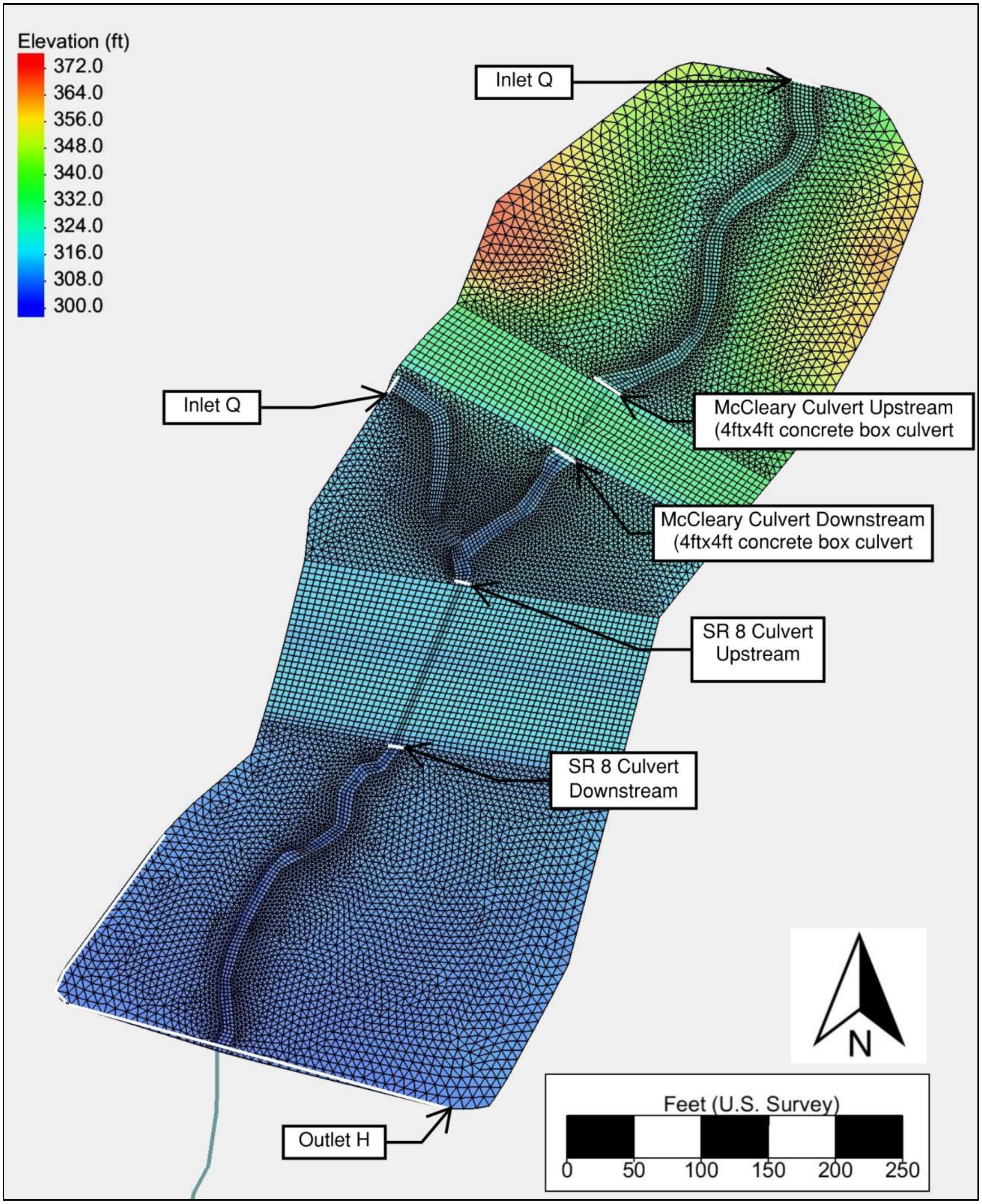

Figure 35: Existing-conditions boundary conditions

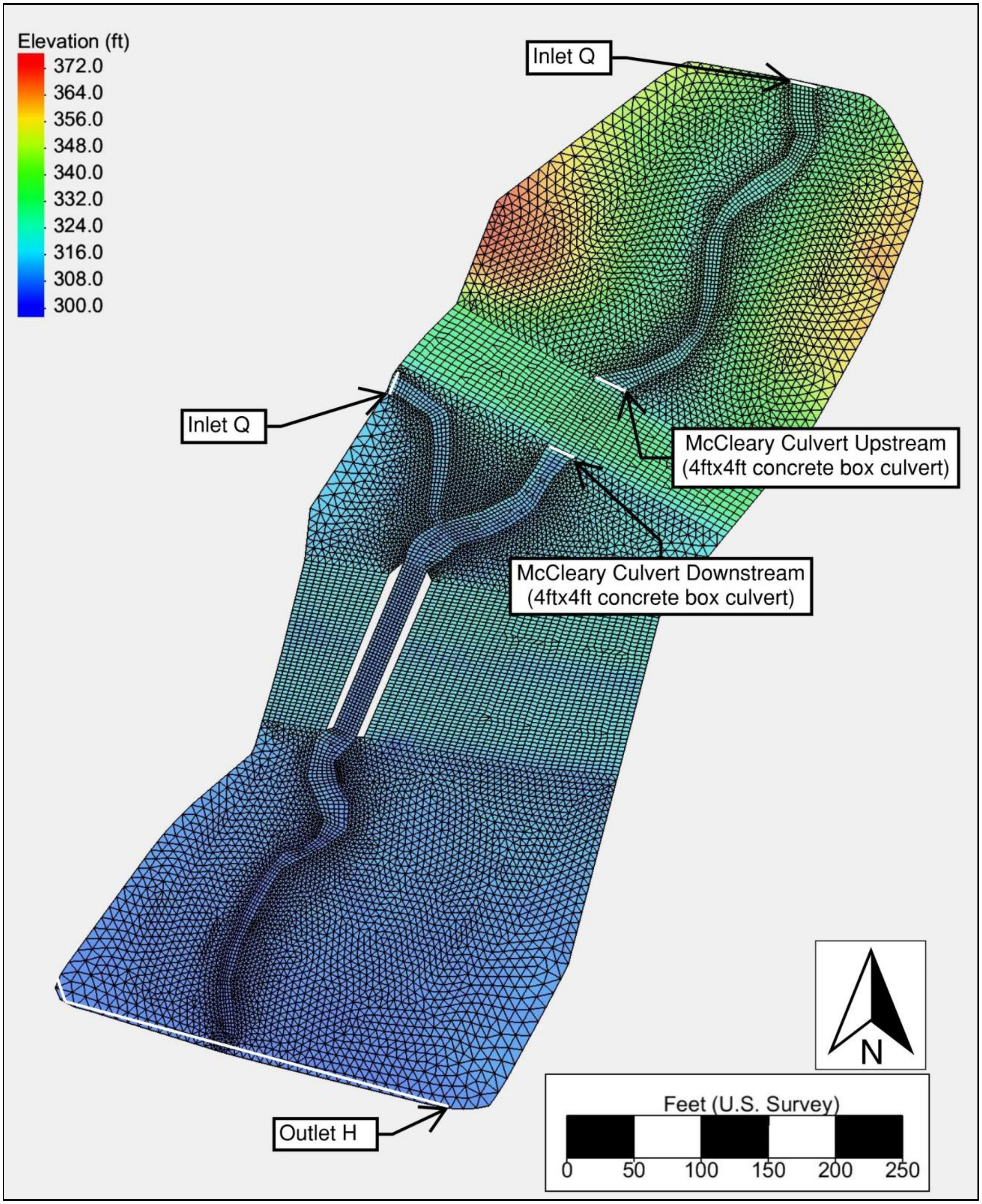

Figure 36: Proposed-conditions boundary conditions

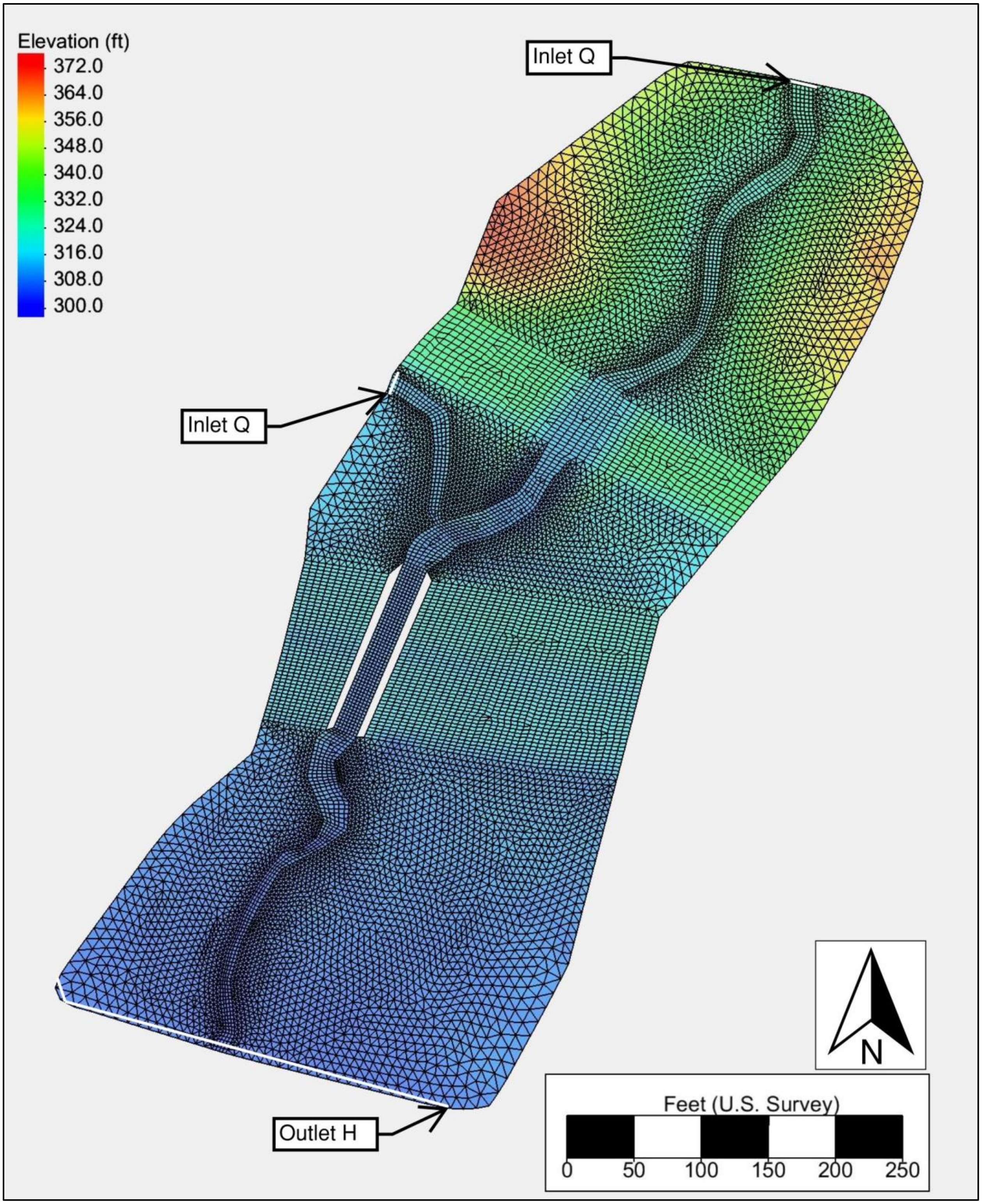

Figure 37: Future conditions boundary conditions

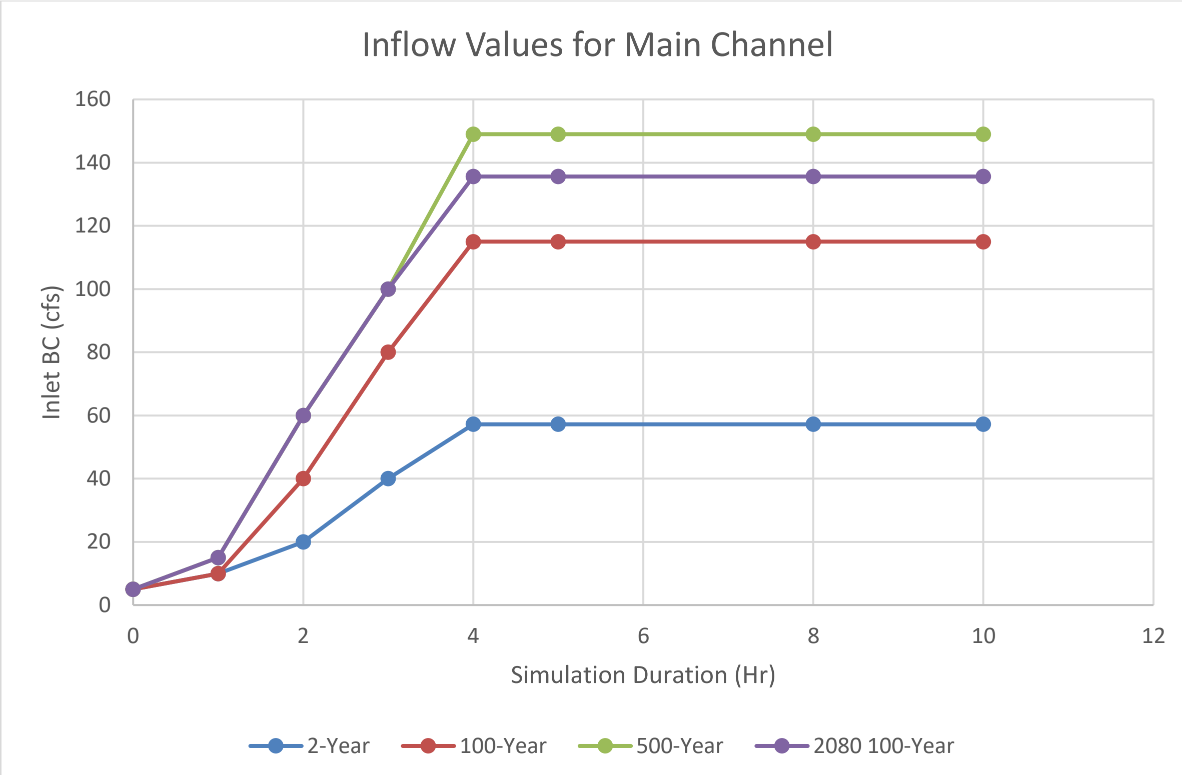

Figure 38: Inflow values for Main Channel

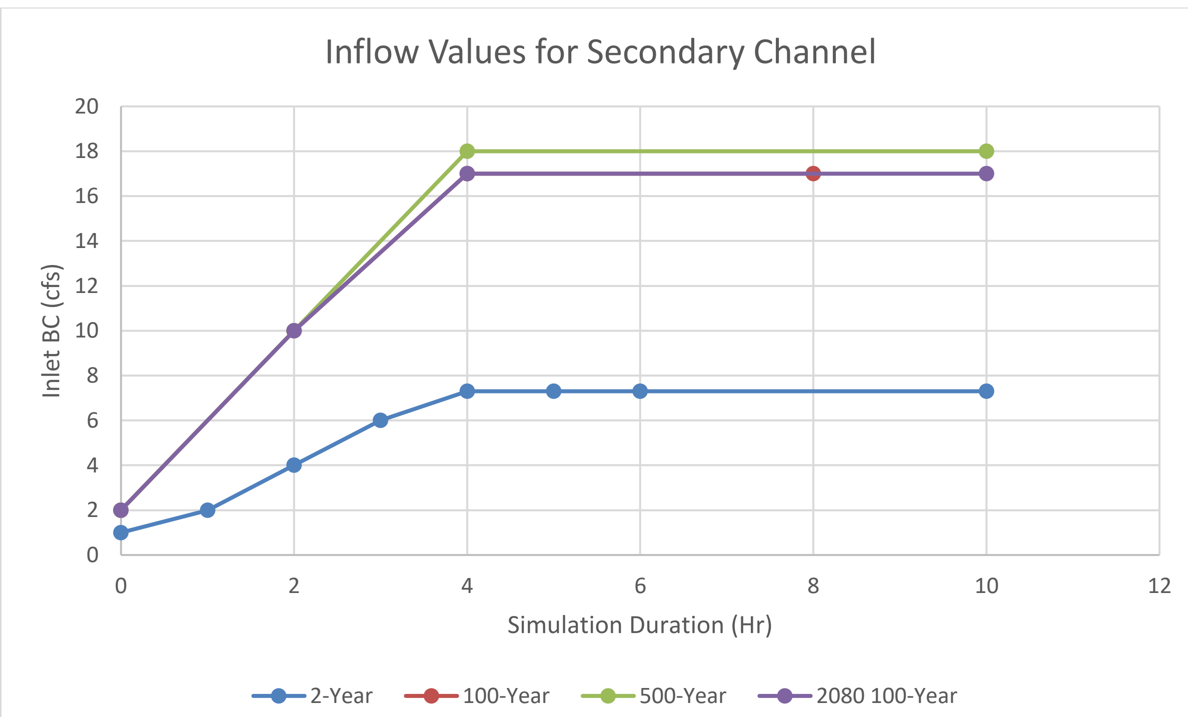

Figure 39: Inflow Values for Secondary Channel

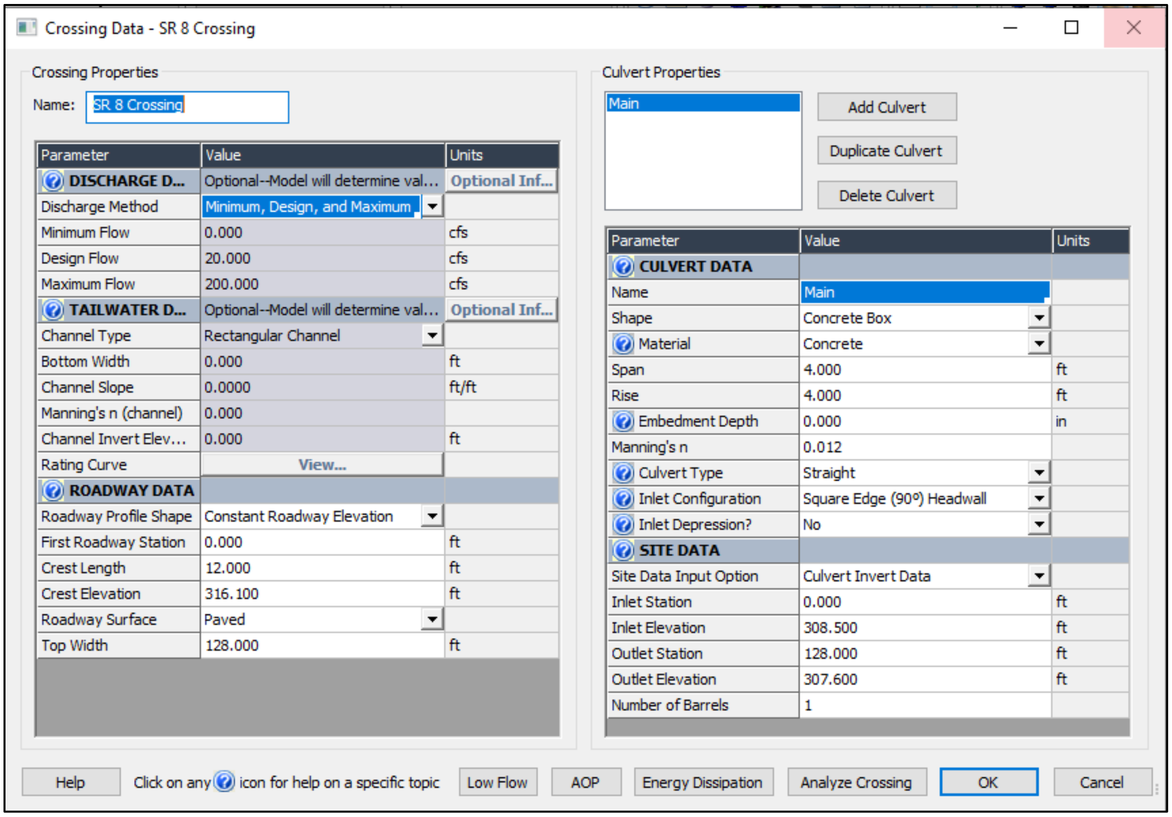

Figure 40: HY-8 culvert parameters for the SR 8 Culvert

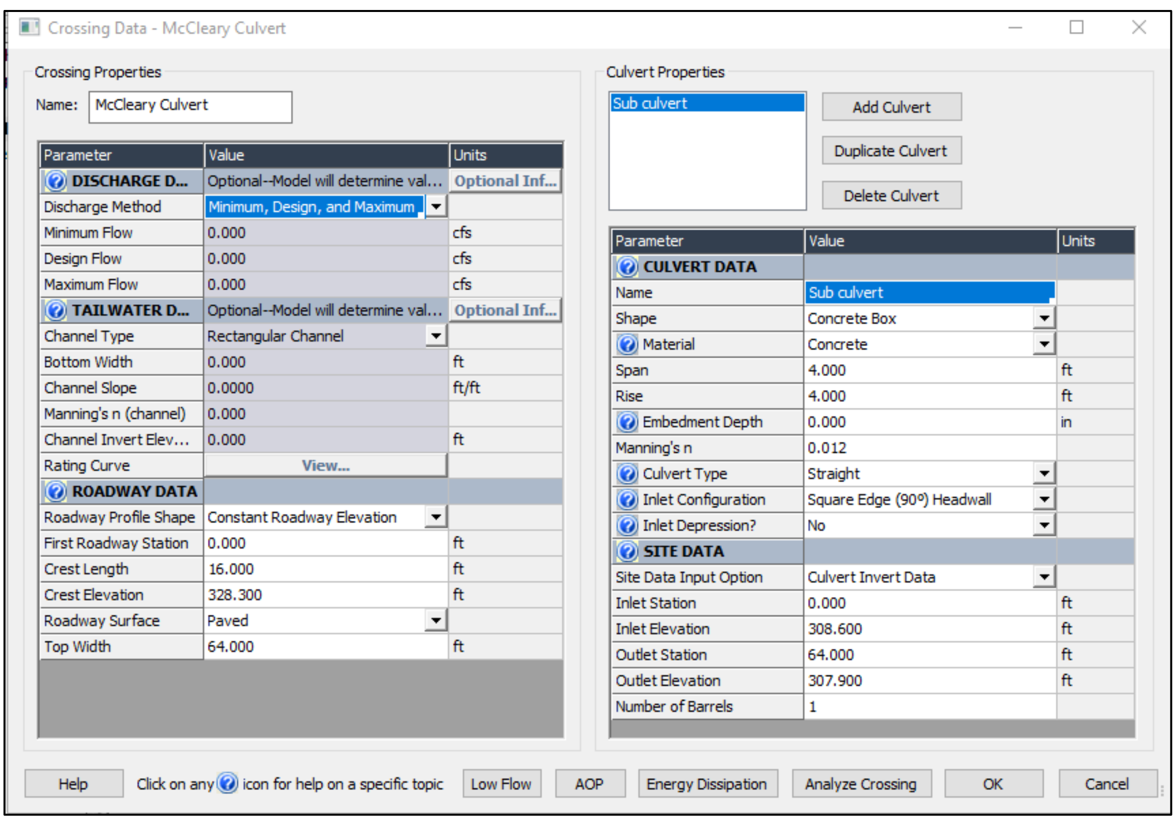

Figure 41: HY-8 culvert parameters for The McCleary Culvert

5.1.5 Model Run Controls

The model had a start time of 0.0 hours, a time step of 0.1 seconds, and an end time of 10.0 hours. The initial conditions were dry. The parabolic turbulence was set to the default value of 0.7. All models reached a stable steady-state result.

5.1.6 Model Assumptions and Limitations

On the downstream side of the model, flow is running up against the mesh on the left side of the model. Due to the flow depth being low in this area, it is assumed that extending the mesh is not necessary. The flow in this area does not affect the culvert. Figure 42 shows the downstream areas of a 500-year event during the existing condition. Red indicated areas that have a depth greater than one foot. Most of the water is in the channel, and only a small amount resides near the edge of the mesh. The mesh was designed this way in the PHD model and was not changed for the FHD to maintain consistency.

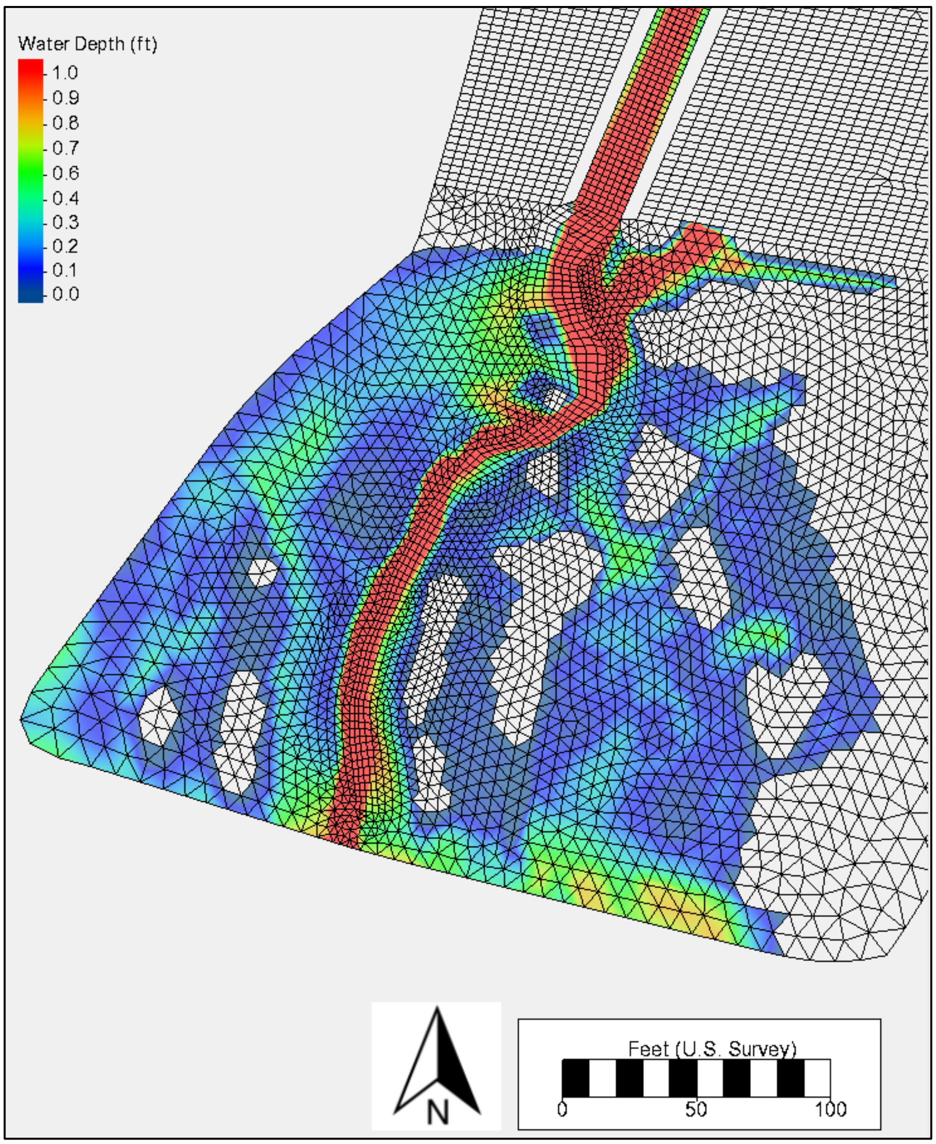

Figure 42: Water depth of proposed conditions model at 100-year flow event scaled zero to one

5.2 Existing Conditions

The existing condition model results show that Culvert 990773 creates a flow constriction that produces backwater upstream. The McCleary Culvert also causes backwater during high flow, but to a lesser degree than Culvert 990773. Effects from this backwater can be seen in the data evaluated from the model at six cross section locations (Figure 43) and summarized in Table 12 for the 2-, 100-, 500-year flood events. This backwater can also be seen in the depth of flow upstream of the culvert (Figure 44) and in the water surface profiles shown in Figure 45. While the 100-year flow does not overtop SR 8, the 500-year flow does overtop the highway west of the crossing. This can be seen in model output images included in Appendix H. This backwater is evidence that Culvert 990773 is undersized for high flows.

Table 12 shows the effect that backwater has on channel velocity. The upstream velocities are considerably lower than downstream velocities and downstream velocities are higher than is typical because the flow is pressurized through the culvert. This effect has created scour pools at the downstream ends of both the SR 8 culvert and the McCleary Culvert. A similar patter is seen for shear stress along the channel bed. Backwater causes decreased shear stress upstream where velocities are low, and increased shear stress downstream where velocities are high.

The relationship between in-channel velocities versus overbank velocities were also evaluated along the cross sections shown in Figure 46. Table 13 shows right overbank and left overbank velocities. The demarcation between in-channel and overbank flow was calculated using the 2-year event water surface top widths. The velocities in Table 13 show a similar pattern related to backwater, with upstream velocities being low and downstream velocities being high.

Cross sections of WSE profiles, and plan views of WSE, depth, velocity, and shear stress for all models are included in Appendix H: SRH-2D Model Results.

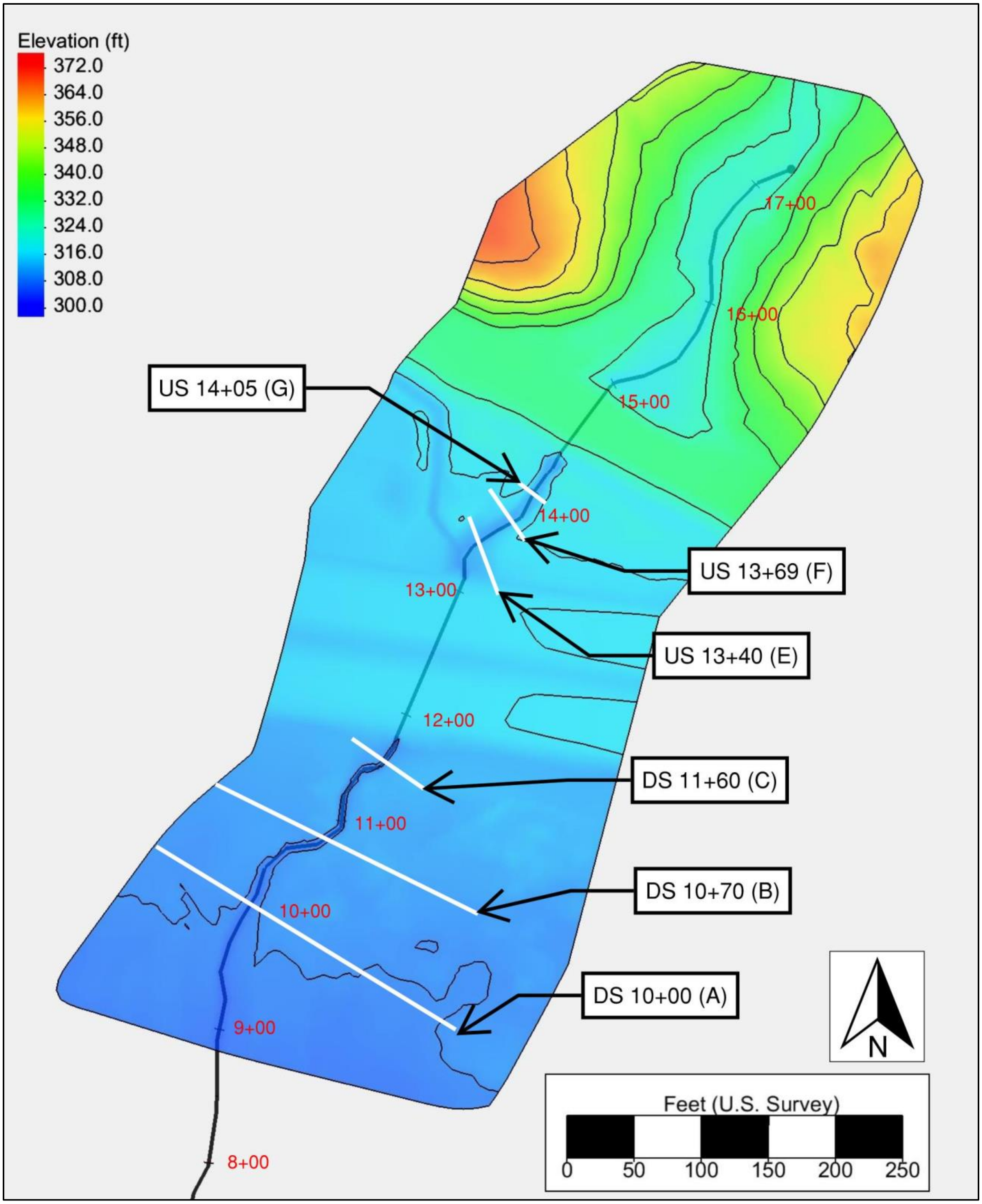

Figure 43: Locations of cross sections used for results reporting

Table 12: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS 10+00 (A)	307.81	308.31	308.40
	DS 10+70 (B)	309.39	309.85	309.92
	DS 11+60 (C)	310.24	311.04	311.14
	Structure (D)	NA	NA	NA
	US 13+40 (E)	312.08	314.41	315.33
	US 13+69 (F)	312.01	314.35	315.30
	US 14+05 (G)	313.16	314.38	315.17
Max depth (ft)	DS 10+00 (A)	2.17	2.69	2.78
	DS 10+70 (B)	2.71	3.09	3.18
	DS 11+60 (C)	2.34	3.15	3.26
	Structure (D)	NA	NA	NA
	US 13+40 (E)	2.19	4.53	5.44
	US 13+69 (F)	1.70	4.09	5.04
	US 14+05 (G)	1.93	3.16	3.95
Average velocity (ft/s)	DS 10+00 (A)	2.18	4.26	4.48
	DS 10+70 (B)	3.53	6.35	6.39
	DS 11+60 (C)	2.72	6.32	6.80
	Structure (D)	NA	NA	NA
	US 13+40 (E)	1.73	1.51	1.55
	US 13+69 (F)	4.03	3.37	3.21
	US 14+05 (G)	2.76	3.10	3.13
Average shear (lb/SF)	DS 10+00 (A)	0.74	1.10	1.23
	DS 10+70 (B)	0.47	1.00	1.02
	DS 11+60 (C)	0.34	1.15	1.54
	Structure (D)	NA	NA	NA
	US 13+40 (E)	0.27	0.12	0.12
	US 13+69 (F)	1.91	0.42	0.36
	US 14+05 (G)	0.72	0.54	0.62

Main channel extents were approximated by 2-year event water surface top widths.

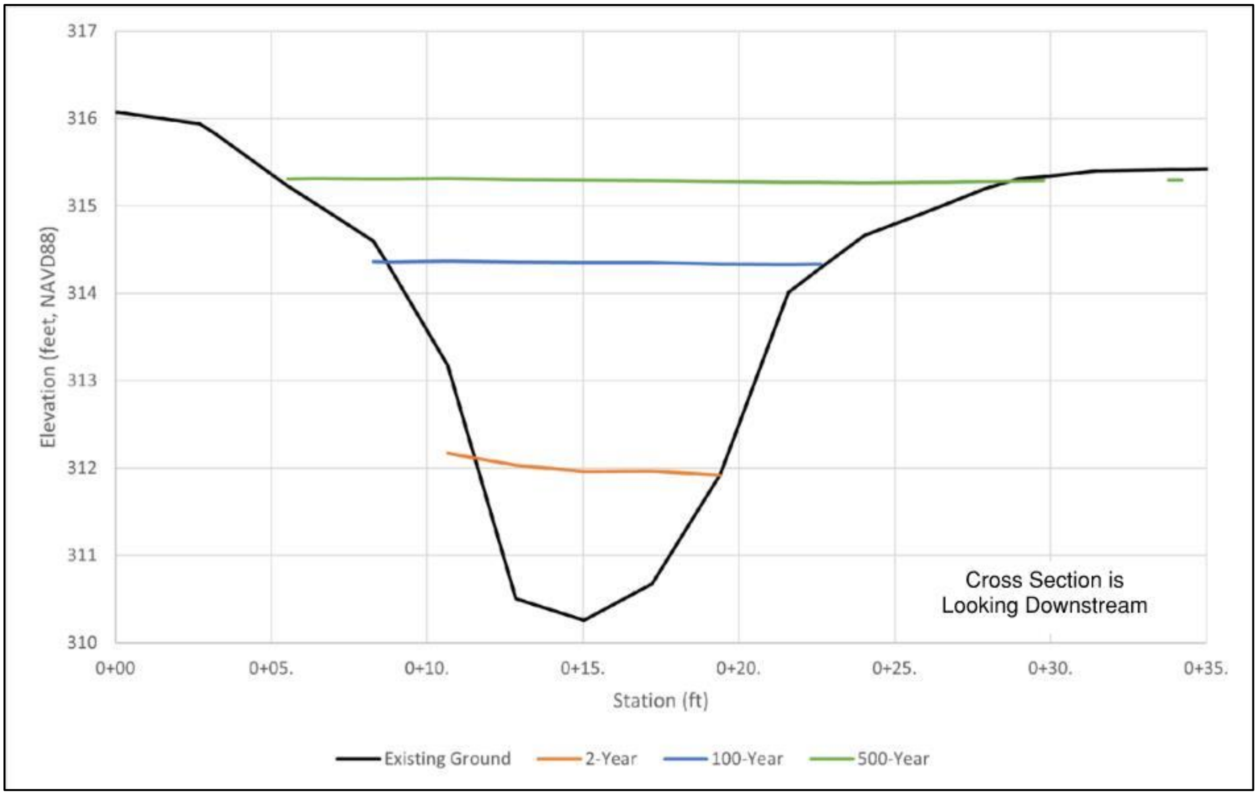

Figure 44: Typical upstream existing channel cross section (STA 6+71)

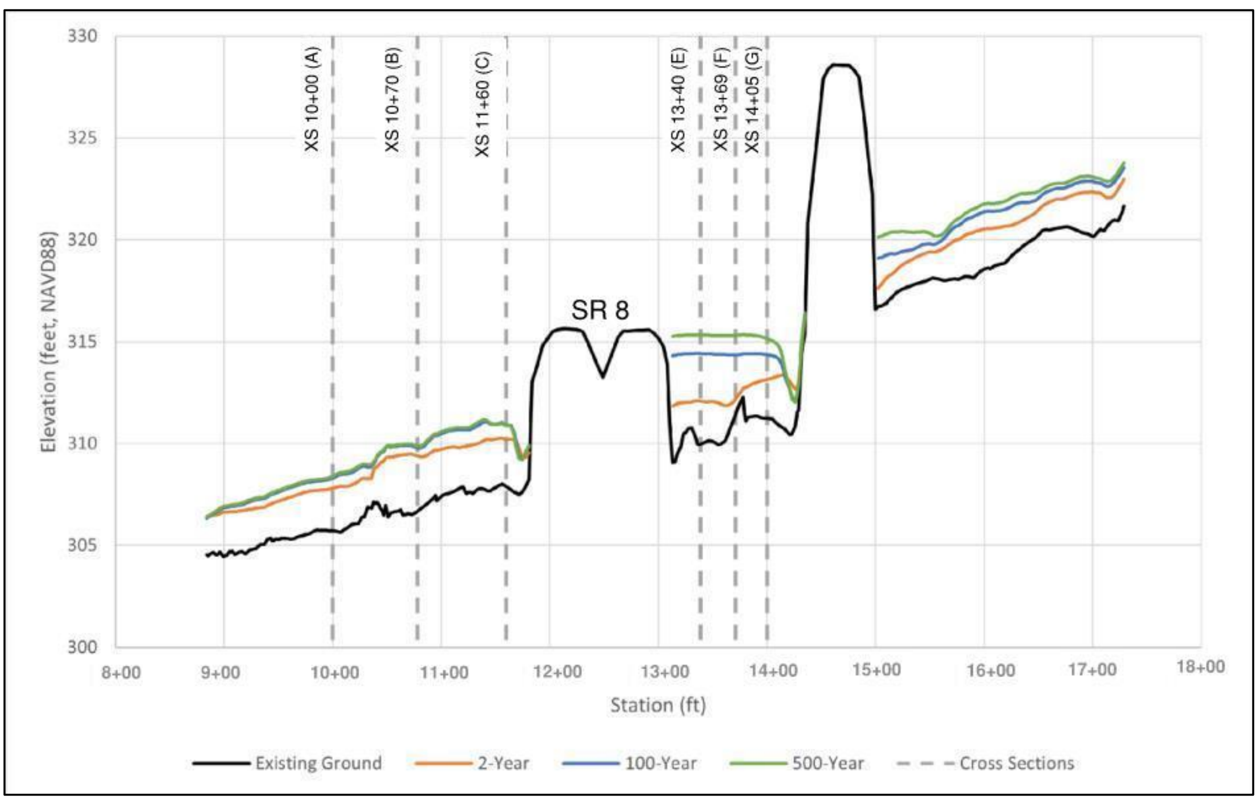

Figure 45: Existing-conditions water surface profiles

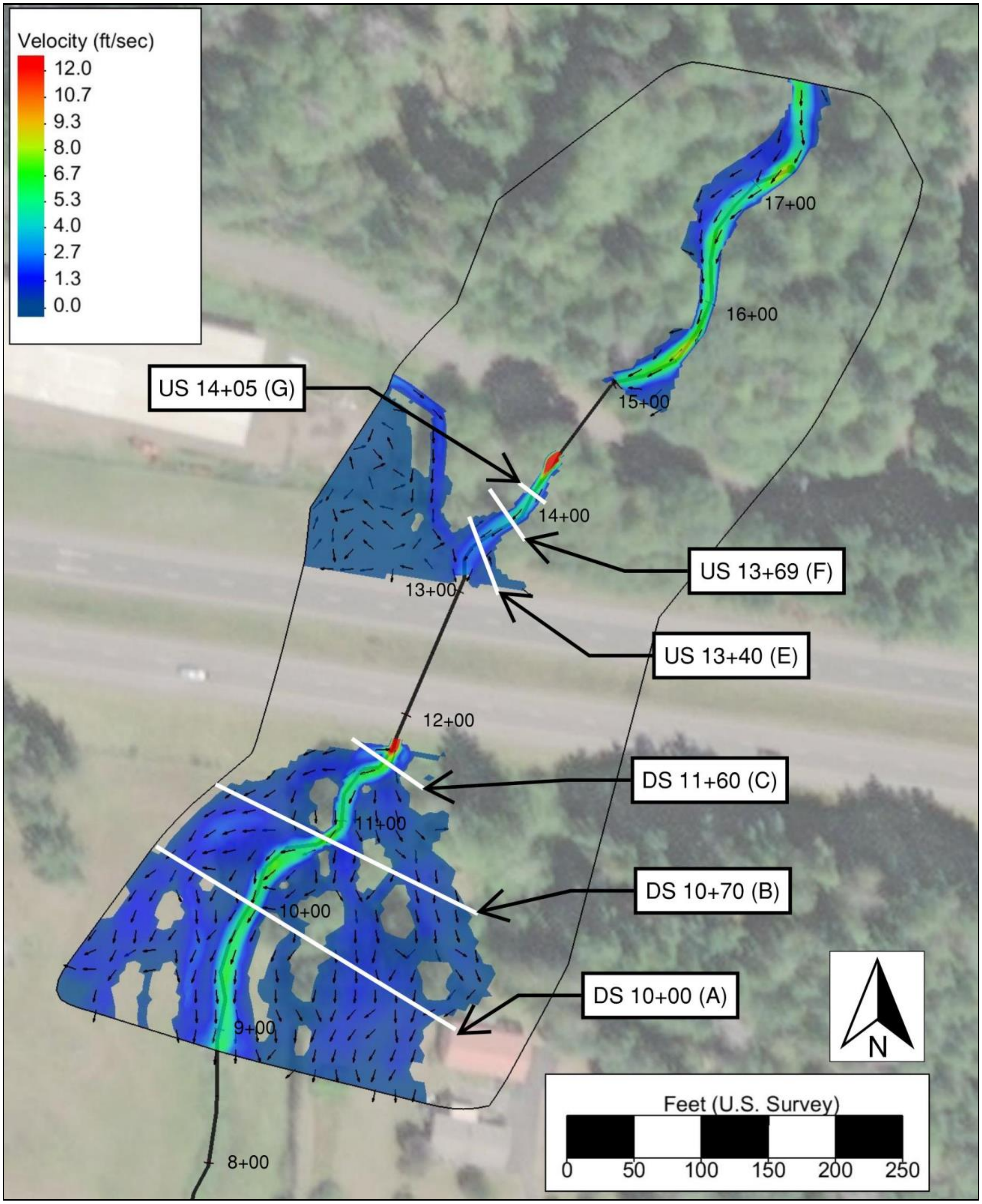

Figure 46: Existing-conditions 100-year velocity map with cross-section locations

Table 13: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 3+00 (A)	0.58	4.26	0.62
DS 3+78 (B)	0.93	1.81	0.72
DS 4+40 (C)	2.21	3.12	1.52
Structure (D)	NA	NA	NA
US 6+39 (E)	0.69	1.71	0.33
US 6+71 (F)	2.19	3.56	1.46
US 7+00 (G)	1.48	3.93	2.99

Right overbank (ROB)/left overbank (LOB) locations were approximated by 2-year event water surface top widths.

5.3 Natural Conditions

A natural-conditions model was not required because the channel is confined.

5.4 Proposed Conditions: 18-foot Minimum Hydraulic Width

The proposed conditions scenario simulated with SRH-2D modified the topography to include the proposed channel configuration, which includes channel grading and the proposed 18-foot-wide concrete box culvert. The future conditions scenario further modified the topography to remove the existing McCleary Culvert with associated channel grading to create a smooth profile through that upstream road crossing. The future condition was used to assess how much freeboard will be needed throughout the life of the new structure.

The proposed SR 8 culvert structure features a graded channel with a 4-foot bottom width and 2H:1V side slopes that extend up to a 10-foot-wide bankfull width before flattening to provide floodplain benches as described in Section 4.1.1. The adjusted stream channel profile for the proposed SR 8 culvert structure starts approximately 20 feet upstream of the existing culvert and ends 35 feet downstream of the culvert with a constant slope of 1.3 percent. The proposed channel is also relocated 37 feet to the west of the existing culvert. The existing culvert will be abandoned in place and plugged. A permeant 12-inch diversion pipe will be installed in the abandoned culvert and capped. This pipe can then be used in the future for maintenance activities within the channel, if necessary.

Average WSEs, maximum depth, average velocity, and shear stress results were analyzed at the cross section locations shown in Figure 47 and the results are summarized in Table 14. These results show that the backwater seen under existing conditions is eliminated with the new culvert. This effect can be seen in the water surface profiles shown in Figure 48 and Figure 49. The culvert inlet and outlet depths become more uniform under proposed conditions as do the flow velocities and channel shear stress. The reduction in outlet flow velocity is significant. The decrease indicates a free flowing, open channel hydraulic condition where the flow enters and leaves the new SR 8 culvert unimpeded. The reduced culvert outlet flow velocities will significantly reduce the risk of downstream streambed erosion and structure undermining. Elevated velocities are still present at the outlet of the McCleary culvert as is expected.

As with existing conditions, velocities were evaluated for in-channel versus overbank areas. Figure 50 shows the cross sections were these evaluations were made and Table 15 shows the velocity comparison. Velocity under the projected 2080 flows are included in the comparison. This shows that while velocities are expected to increase over time, as flow rates increase, the velocity will remain in a reasonable range for this crossing throughout the life of the structure.

Cross sections of WSE profiles, and plan views of WSE, depth, velocity, and shear stress for all models are included in Appendix H: SRH-2D Model Results.

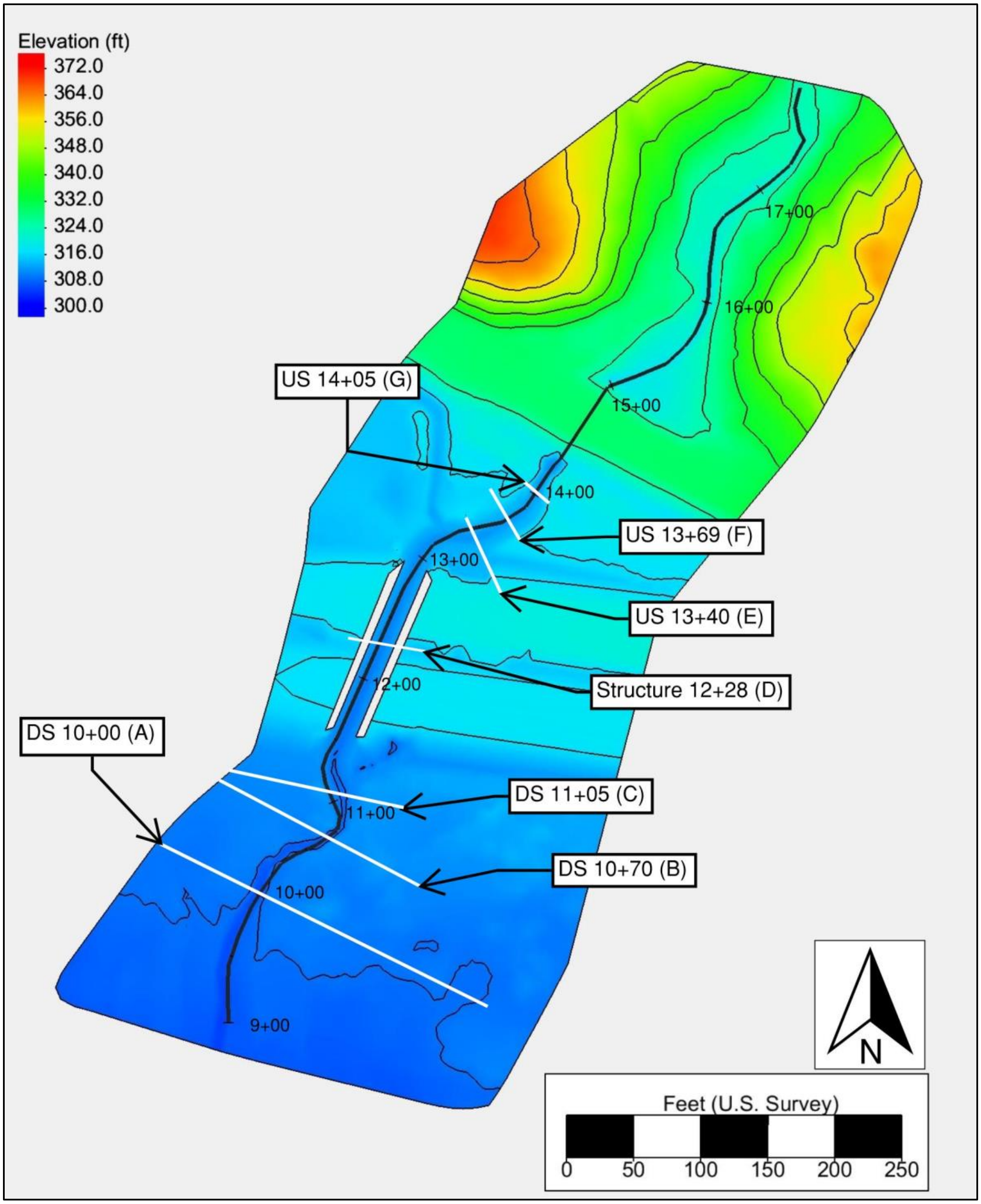

Figure 47: Locations of cross sections on proposed alignment used for results reporting

Table 14: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS 10+00 (A)	307.98	308.38	308.48	308.54
	DS 10+70 (B)	309.52	309.84	309.91	309.96
	DS 11+05 (C)	310.59	310.95	311.03	311.08
	Structure 12+28 (D)	311.12	311.63	311.77	311.86

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
	US 13+40 (E)	313.05	313.70	313.87	313.99
	US 13+69 (F)	313.24	313.83	314.00	314.11
	US 14+05 (G)	313.33	313.66	313.72	313.75
Max depth (ft)	DS 10+00 (A)	2.27	2.67	2.77	2.83
	DS 10+70 (B)	1.46	1.77	1.86	1.90
	DS 11+05 (C)	2.94	3.30	3.38	3.43
	Structure 12+28 (D)	1.93	2.44	2.58	2.67
	US 13+40 (E)	2.34	2.99	3.16	3.28
	US 13+69 (F)	2.17	2.80	2.97	3.07
	US 14+05 (G)	2.17	2.43	2.48	2.49
Average velocity (ft/s)	DS 10+00 (A)	2.88	4.06	4.17	4.23
	DS 10+70 (B)	1.25	1.66	1.73	1.78
	DS 11+05 (C)	1.27	1.77	1.91	2.01
	Structure 12+28 (D)	2.88	3.88	4.12	4.29
	US 13+40 (E)	1.56	2.04	2.23	2.37
	US 13+69 (F)	2.09	2.87	3.18	3.31
	US 14+05 (G)	3.07	4.73	5.36	5.77
Average shear (lb/SF)	DS 10+00 (A)	0.62	0.80	0.83	0.85
	DS 10+70 (B)	0.87	1.05	1.00	1.01
	DS 11+05 (C)	0.35	0.58	0.66	0.72
	Structure 12+28 (D)	0.56	0.93	1.03	1.11
	US 13+40 (E)	0.29	0.39	0.45	0.47
	US 13+69 (F)	0.49	0.72	0.81	0.85
	US 14+05 (G)	0.89	1.76	2.19	2.58

Main channel extents were approximated by a combination of 2-year event water surface top widths and inspection of the topographic grade breaks.

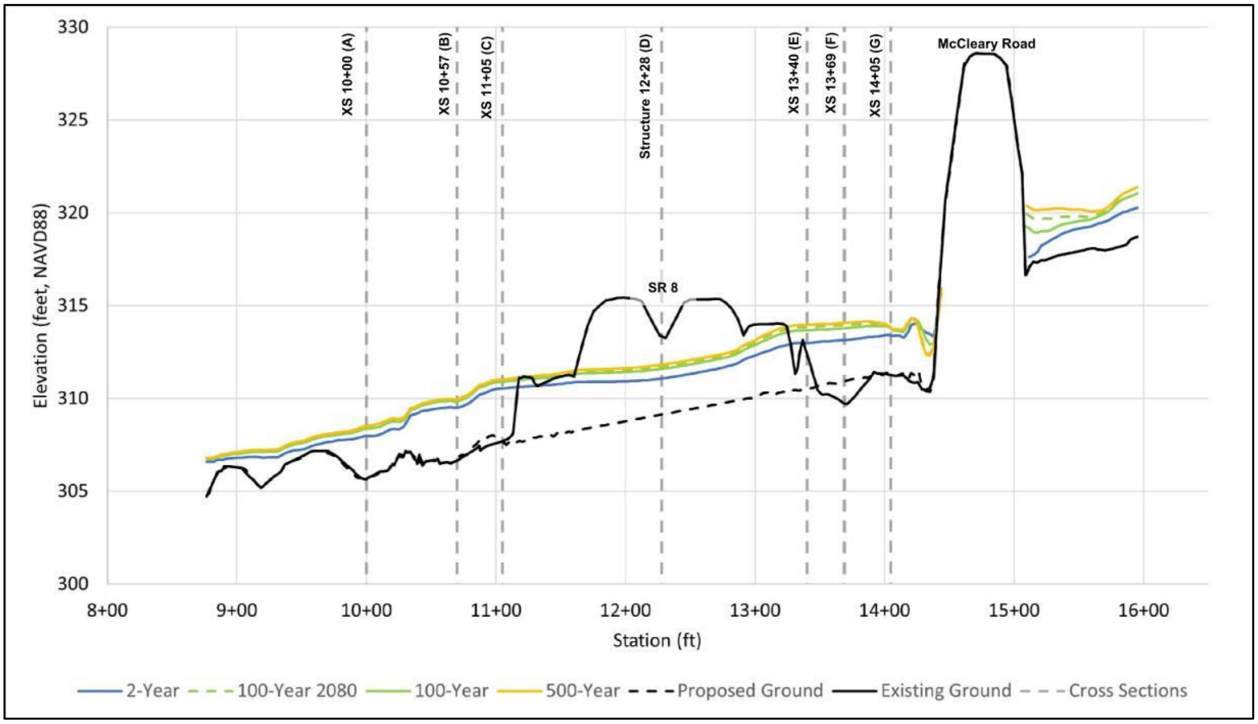

Figure 48: Proposed-conditions water surface profiles

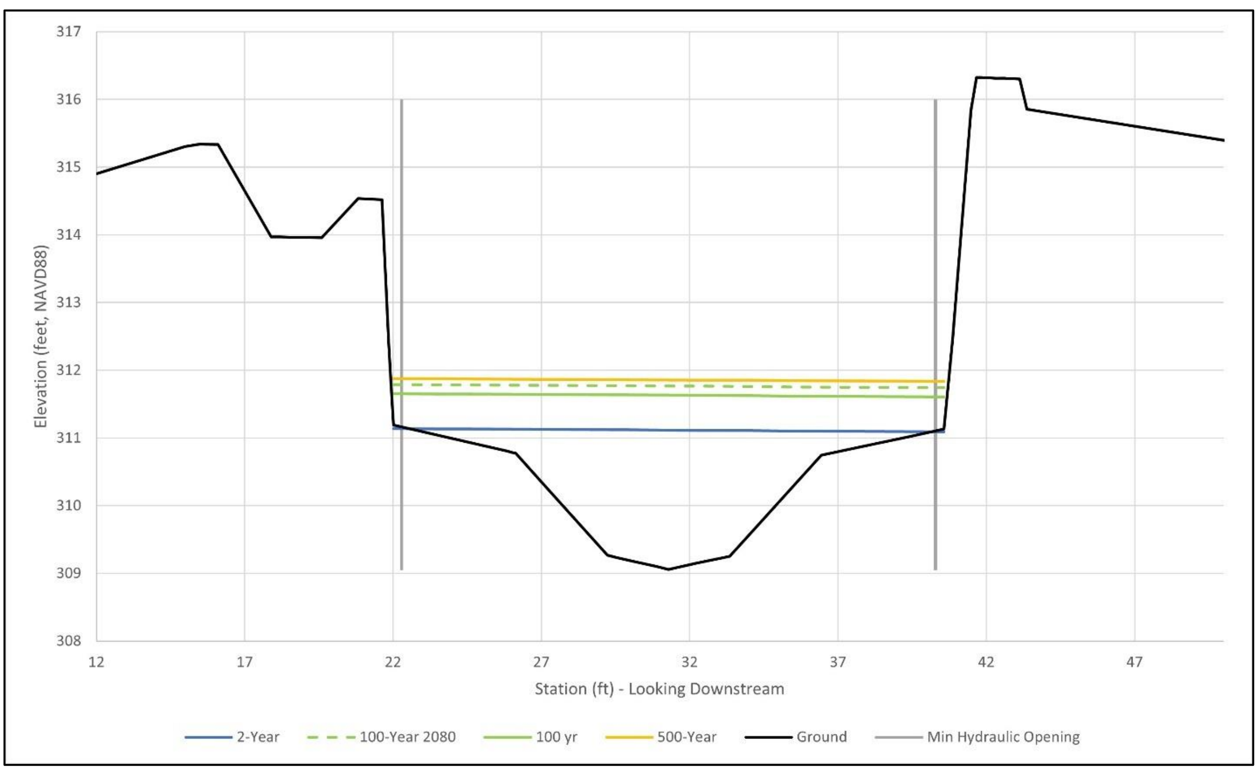

Figure 49: Typical section through proposed structure (STA 12+28)

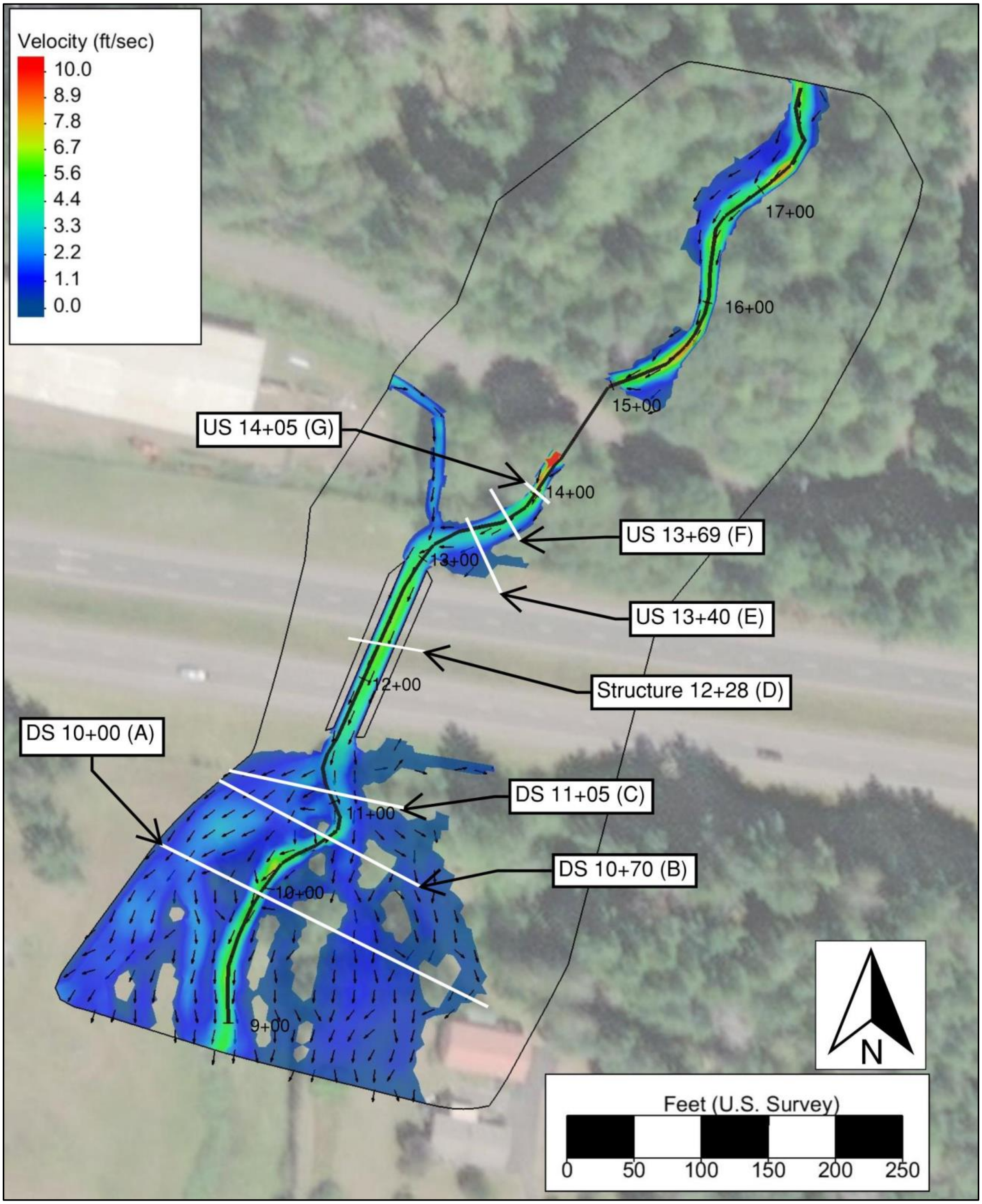

Figure 50: Proposed-conditions 100-year velocity map

Table 15: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 10+00 (A)	0.40	1.20	1.17	0.49	1.34	1.41
DS 10+70 (B)	0.50	1.72	0.00	0.61	1.87	0.00
DS 11+05 (C)	0.17	1.43	0.04	0.25	1.68	0.05
Structure 12+28 (D)	0.00	4.85	0.00	0.00	5.15	0.00
US 13+40 (E)	0.03	1.63	0.58	0.09	1.79	0.72
US 13+69 (F)	0.72	3.15	1.69	0.83	3.40	2.15
US 14+05 (G)	0.00	4.73	0.00	0.00	5.36	0.00

Right overbank (ROB)/left overbank (LOB) locations were approximated by a combination of 2-year event water surface top widths and inspection of the topographic grade breaks.

6 Floodplain Evaluation

The Unnamed Tributary to Mox Chehalis Creek is not within a FEMA special flood hazard area, including the project area, so a flood risk analysis was not required. The Mox Chehalis Creek is mapped as a Zone A floodplain by FEMA, but this does not extend to the project area. See Appendix A for a copy of the FEMA flood insurance rate map. The existing and proposed water surface elevations were still compared to evaluate floodplain rise and are shown in Figure 51. The decrease in water surface elevation upstream of the crossing is caused by the elimination of existing backwater due to the enlarged culvert. Correspondingly, there are small increases in water surface elevation downstream because the new culvert will restore flood levels

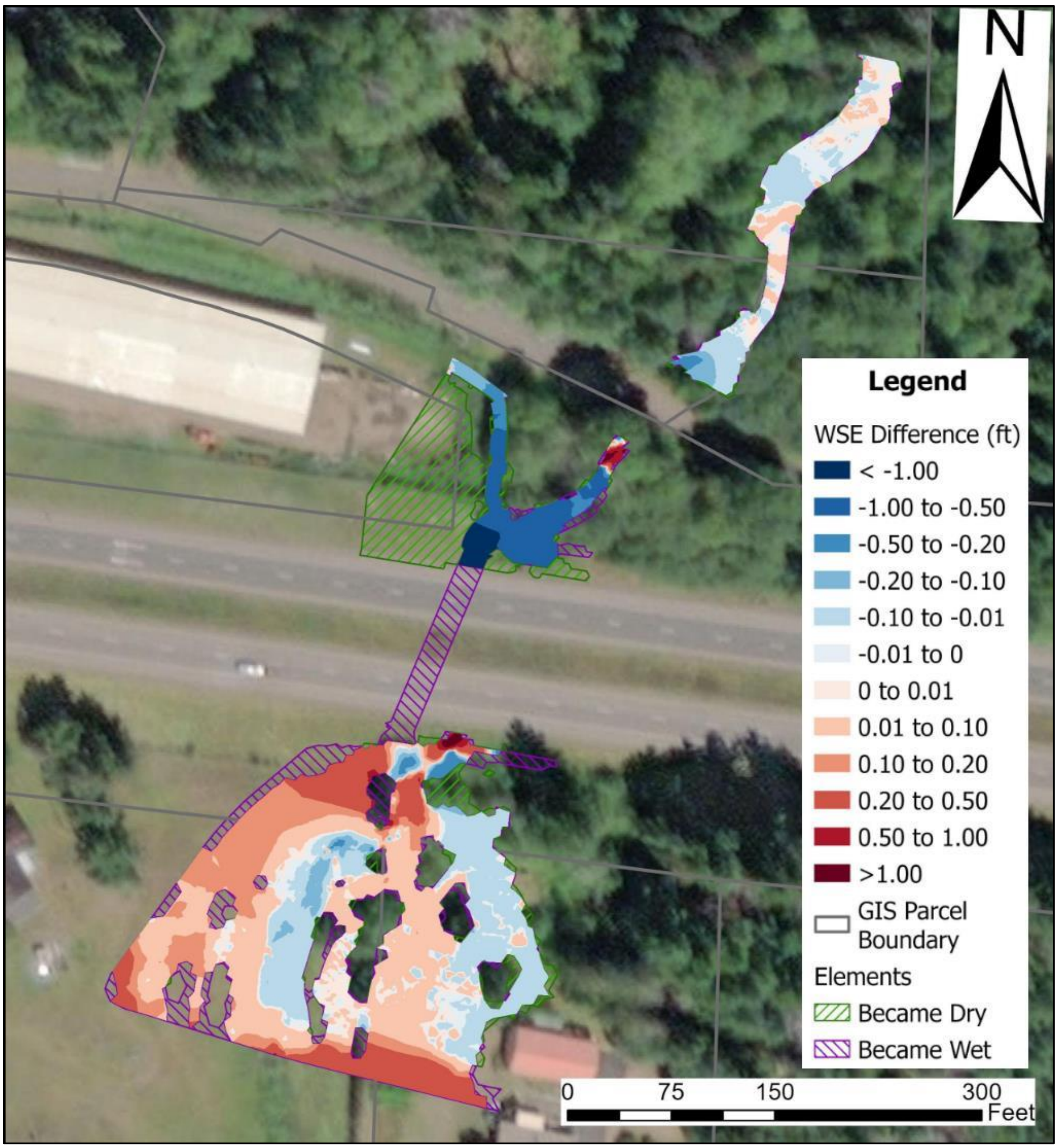

Figure 51: 100-year WSE change from existing to proposed conditions

7 Scour Analysis

For this FHD, the risk for lateral migration, potential for long-term degradation, and evaluation of total scour are based on the final geotechnical report dated March 11, 2020.

Using the results of the hydraulic analysis (Section 5.4), based on the recommended final structure, and considering the potential for lateral channel migration final scour calculations for the scour design flood and scour check flood were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson et al. 2012). Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections.

7.1 Lateral Migration

The lateral migration risk is low for the SR 8 Culvert. The channel is in a V-shaped ravine that restricts lateral migration. There were also only limited indications of lateral migration observed during the field analysis. In the unlikely case of lateral migration upstream of the crossing, wingwalls that extend 17 feet past the structure walls would guide the channel through the buried structure. Lateral migration is possible along the Mox Chehalis Creek mainstem at the downstream end of the unnamed tributary, but this channel movement is not expected to reach the location of the project. See Section 2.7.5 for more details.

7.2 Long-term Aggradation/Degradation of the Channel Bed

Long-term changes in streambed elevations associated with manmade or natural causes are considered long-term aggradation and degradation. Aggradation is the deposition of material caused by limited sediment transport capacity for the volume of sediment derived from erosion of the channel and/or upstream watershed. Aggradation is not a component of total scour. Conversely, degradation is the lowering or scouring of the channel bed across long reaches of channel caused by a decrease in the sediment supply from upstream. Degradation is a component of total scour.

As discussed in Section 2.7.4 aggradation is anticipated at this crossing at some point in the future when the upstream McCleary culvert is replaced. The anticipated change to the channel bed elevation from long-term aggradation was estimated based on a long profile of the channel. Inputs include the surveyed stream profile and an estimate of the volume of material that would be deposited in the vicinity of the crossing. Appendix K summarizes an approach that graphically illustrates the result, which indicates that when the long-term aggradation reaches equilibrium the channel bed could be as much as 2 feet higher near the inlet of Culvert 990773, decreasing to 1.5 feet higher at the culvert outlet and then decreasing further to zero roughly

140 feet downstream of the culvert outlet. The change in channel profile from aggradation is illustrated in Figure 52 and the increased bed elevations through the new culvert is shown in detail on the profile sheet included in Appendix D.

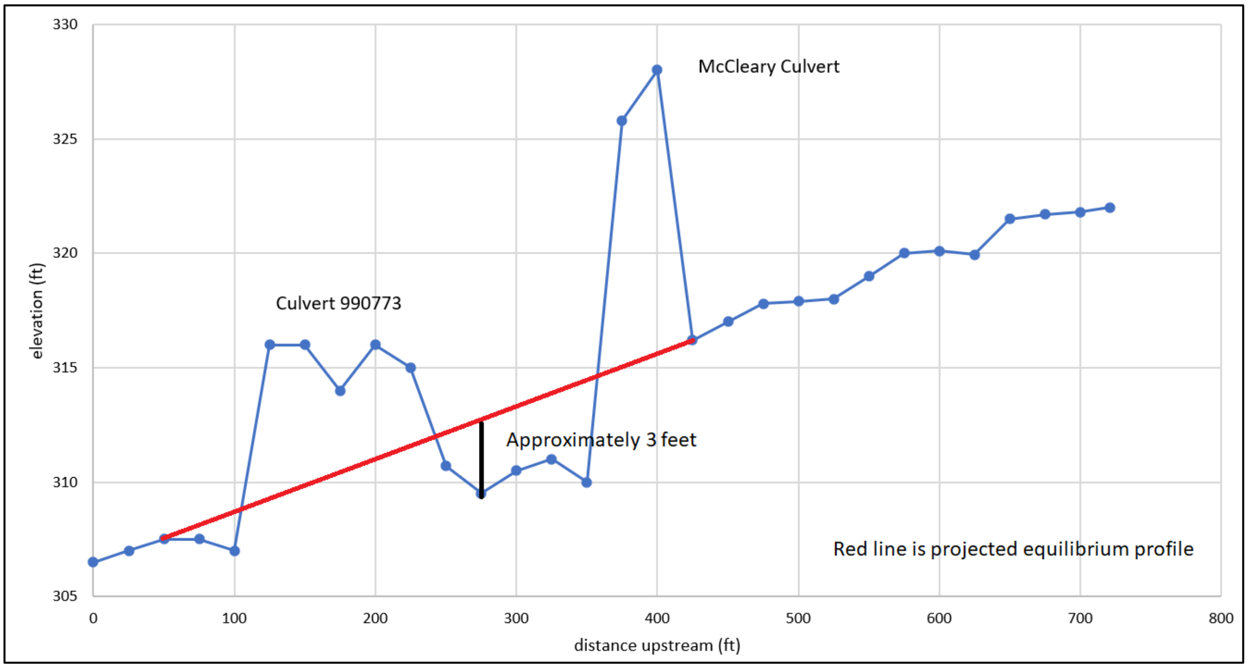

Figure 52: Potential long-term degradation at the proposed structure upstream face

7.3 Contraction Scour

Contraction scour is the lowering of the streambed elevation associated with a constriction of flow through a culvert or bridge. The potential for contraction scour is extremely modest at this site location due to the proposed culvert span that will be much wider than the channel bankfull width. Estimates of contraction scour were calculated following the methodology outlined in Chapter 6 of HEC-18 (Arneson et al. 2012) for non-cohesive materials and using the Hydraulic Toolbox software developed by FHWA (version 5.1). The contraction scour condition can be classified as live-bed or clear-water scour. The scour condition is dependent on the transport of streambed material from upstream of the culvert or bridge. Clear-water scour occurs when there is no streambed material in transport, while live-bed scour occurs when there is transport of bed material from an upstream reach into the crossing. Scour condition determination is made by calculating the critical flow velocity that will mobilize the D50 and comparing it to the mean flow velocity estimated upstream of the culvert or bridge opening.

The analysis indicates that the clear-water contraction scour condition will exist and was therefore used to determine contraction scour at this site. The resulting calculation indicates that the 100-year contraction scour is 1.23 feet, the projected 2080 100-year contraction scour is 1.68 feet, and the 500-year contraction scour is 1.99 feet. The detailed calculations are provided in Appendix K.

7.4 Local Scour

Local scour includes scour due to accelerating flow and resulting vortices induced by specific features such as piers, spurs, and embankments. Neither abutment scour nor pier scour applies at culvert crossings and was, therefore, not calculated.

7.4.1 Pier Scour

Crossing will not have piers and therefore pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was not quantified at the crossing because the proposed abutments are located outside the extents of the proposed 500-year floodplain and 2080 projected 100-year floodplain.

7.4.3 Bend Scour

Bend scour was calculated following the methodology outlined in HEC-23 (Lagasse et al. 2012). Depth of bend scour was estimated using Maynord's method. The analysis indicates that the depth of bend scour is 2.1 feet. The calculations for bend scour are included in Appendix K.

7.5 Total Scour

Calculated total depths of scour for the scour design flood and scour check flood at the proposed Unnamed Tributary to Mox Chehalis Creek culvert as shown in the plans dated in November 2022 are provided in Table 16. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 16.

Table 16: Scour analysis summary

Calculated Scour Components and Total Scour for SR 8 Unnamed Tributary to Mox Chehalis Creek		
	Scour design flood	**Scour check flood**
Long-term degradation (ft)	N/A	N/A
Contraction scour (ft)	1.2	2.0
Local scour (ft)[a]	N/A	N/A
Total depth of scour (ft)	**1.2**	**2.0**

a. All channel bends are beyond the limits of the culvert and were, therefore, not included in the total scour related to the structure.

8 Scour Countermeasures

The bottom of the new structure is at least 2 feet below the anticipated scour depth, so no scour countermeasures need to be applied.

9 Summary

Table 17 presents a summary of the results of this FHD Report.

Table 17: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	8,140 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	9.5 ft	2.7.2 Channel Geometry
	Concurrence BFW	NA	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	29.42	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	2.69	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	132 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	152.6 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	152.6 cfs	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	Yes	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	0.81%	2.6.2 Existing Conditions
	Reference reach	1.6%	2.7.1 Reference Reach Selection
	Proposed	1.3%	4.1.3 Channel Gradient
Hydraulic width	Existing	4 ft	2.6.2 Existing Conditions
	Proposed	18 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	2.1 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	140 ft	2.6.2 Existing Conditions
	Proposed	135 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	Yes	4.2.6 Structure Type
	Type	Concrete Box Culvert	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	No	4.3.1 Bed Material
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	4	4.3.2 Channel Complexity
	Boulder clusters	NA	4.3.2 Channel Complexity
	Coarse bands	NA	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	Mobile wood	No	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	No	6 Floodplain Evaluation
Scour	Analysis	See link	7 Scour Analysis
	Scour countermeasures	No	8 Scour Countermeasures
Channel degradation	Potential?	No	7.2 Long-term Aggradation/Degradation of the Channel Bed
Channel degradation	Allowed?	NA	7.2 Long-term Aggradation/Degradation of the Channel Bed

10 References

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form (*not used*)

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning's Calculations (*not used*)

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

Appendix J: Reach Assessment (*not used*)

Appendix K: Scour Calculations

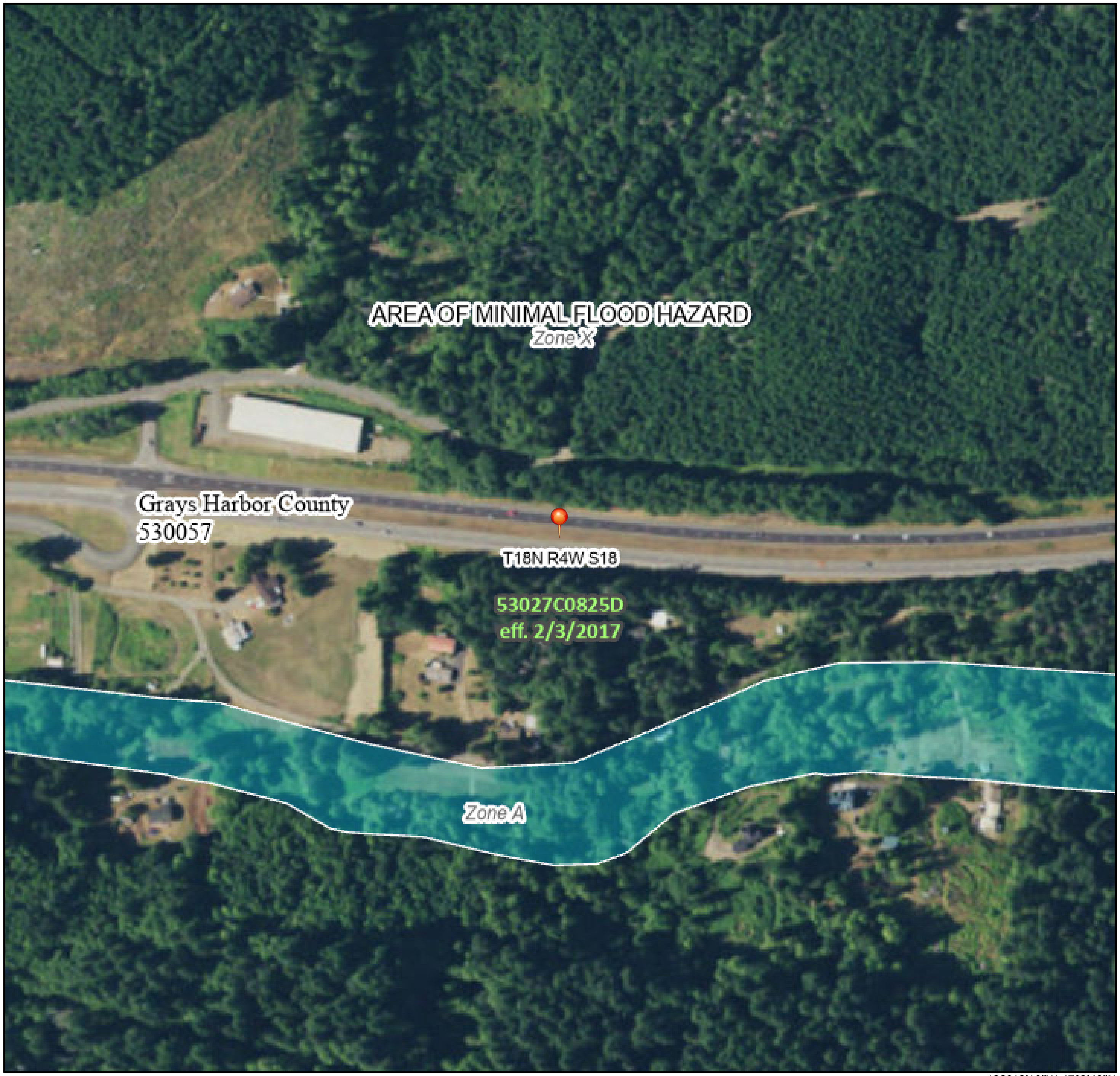
Appendix L: Floodplain Analysis (*not used*)

Appendix A: FEMA Floodplain Map

National Flood Hazard Layer FIRMette

FEMA

123°13'57"W 47°3'13"N



123°13'19"W 47°2'48"N

Feet 0 250 500 1,000 1,500 2,000

1:6,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS		Without Base Flood Elevation (BFE) *Zone A, V, A99*
		With BFE or Depth *Zone AE, AO, AH, VE, AR*
		Regulatory Floodway
OTHER AREAS OF FLOOD HAZARD		0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
		Future Conditions 1% Annual Chance Flood Hazard *Zone X*
		Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
		Area with Flood Risk due to Levee *Zone D*
OTHER AREAS	NO SCREEN	Area of Minimal Flood Hazard *Zone X*
		Effective LOMRs
		Area of Undetermined Flood Hazard *Zone D*
GENERAL STRUCTURES		Channel, Culvert, or Storm Sewer
		Levee, Dike, or Floodwall
OTHER FEATURES	B 20.2 / 17.5	Cross Sections with 1% Annual Chance Water Surface Elevation
	8	Coastal Transect
	513	Base Flood Elevation Line (BFE)
		Limit of Study
		Jurisdiction Boundary
		Coastal Transect Baseline
		Profile Baseline
		Hydrographic Feature
MAP PANELS		Digital Data Available
		No Digital Data Available
		Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 5/4/2022 at 8:38 AM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Appendix B: Hydraulic Field Report Form

Not Used. These forms were not in use at the time the PHD was written.

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	**Grays Harbor - UNT to Mox Chehalis**
By:	**Karen Comings, P.E.**

Design Gradation:				
Location:	Channel Average			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.35**	**0.20**	**0.11**	**0.06**
in	**4.25**	**2.35**	**1.30**	**0.75**
mm	**108**	**60**	**33.0**	**19.1**

Design Gradation:				
Location:	Upstream Pebble Count			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.29**	**0.18**	**0.09**	**0.06**
in	**3.50**	**2.20**	**1.10**	**0.70**
mm	**89**	**56**	**28**	**18**

Design Gradation:				
Location:	Downstream Pebble Count			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.42**	**0.21**	**0.13**	**0.07**
in	**5.0**	**2.5**	**1.5**	**0.8**
mm	**127**	**64**	**38**	**20**

Design Gradation:				
Location:				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft				
in				
mm				

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		**Streambed**	**Streambed Cobbles**					**Streambed Boulders**			**D_{size}**
[in]	**[mm]**	**Sediment**	**4"**	**6"**	**8"**	**10"**	**12"**	**12"-18"**	**18"-28"**	**28"-36"**	
36.0	**914**									**100**	**100.0**
32.0	**813**									50	**100.0**
28.0	**711**								**100**		**100.0**
23.0	**584**								50		**100.0**
18.0	**457**							**100**			**100.0**
15.0	**381**							50			**100.0**
12.0	**305**						**100**				**100.0**
10.0	**254**					**100**	80				**100.0**
8.0	**203**				**100**	80	68				**100.0**
6.0	**152**			**100**	80	68	57				**100.0**
5.0	**127**			80	68	57	45				**100.0**
4.0	**102**		**100**	71	57	45	39				**100.0**
3.0	**76.2**		80	63	45	38	34				**88.0**
2.5	**63.5**	**100**	65	54	37	32	28				**79.0**
2.0	**50.8**	92.5	50	45	29	25	22				**67.0**
1.5	**38.1**	79	35	32	21	18	16				**52.7**
1.0	**25.4**	66	20	18	13	12	11				**38.4**
0.50	**12.7**	48	5	5	5	5	5				**22.2**
0.19	**4.75**	29									**11.6**
0.02	**0.425**	10									**4.0**
0.003	**0.0750**	5									**2.0**
% per category		**40**	**60**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	*--> 100%*
% Cobble & Sediment		**40.0**	**60.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	*100.0%*

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

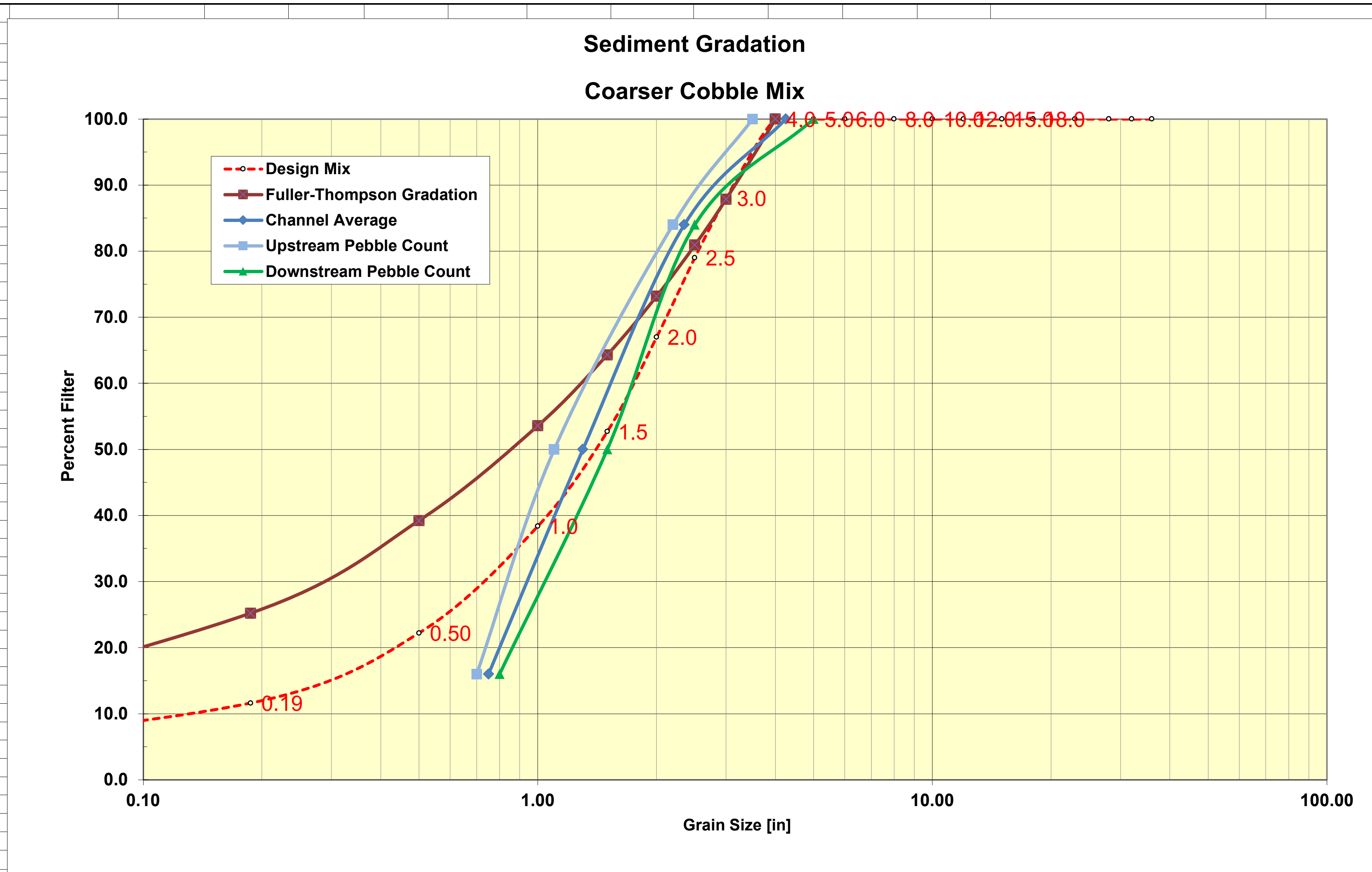
Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Average Modeled Shear Stress (lb/ft^2)	0.60	0.70	0.80	0.90	1.00	1.20
τ_{ci}						
1.66	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.61	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.54	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.45	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.35	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.28	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.20	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
1.13	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
1.06	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
0.97	No Motion	No Motion	No Motion	No Motion	Motion	Motion
0.92	No Motion	No Motion	No Motion	No Motion	Motion	Motion
0.86	No Motion	No Motion	No Motion	Motion	Motion	Motion
0.79	No Motion	No Motion	Motion	Motion	Motion	Motion
0.75	No Motion	No Motion	Motion	Motion	Motion	Motion
0.70	No Motion	Motion	Motion	Motion	Motion	Motion
0.64	No Motion	Motion	Motion	Motion	Motion	Motion
0.57	Motion	Motion	Motion	Motion	Motion	Motion
0.46	Motion	Motion	Motion	Motion	Motion	Motion

D50	1.50	in
	0.13	ft
	38.1	mm

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010



Fuller-Thompson Gradation	
Dmax =	4
D[in]	
12.000	163.95
10.000	151.03
8.000	136.60
6.000	120.02
5.000	110.56
4.000	100.00
3.000	87.86
2.500	80.94
2.000	73.20
1.500	64.32
1.000	53.59
0.500	39.23
0.187	25.20
0.017	8.50
0.003	3.90

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Summary - Stream Simulation Bed Material Design

Project:	Grays Harbor - UNT to Mox Chehalis
By:	Karen Comings, P.E.

Design Gradation:

Location: Channel Average

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.83	0.63	0.20	0.04
in	10.00	7.51	2.34	0.44
mm	254	191	59.5	11.1

Design Gradation:

Location: Upstream Pebble Count

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.29	0.18	0.09	0.06
in	3.50	2.20	1.10	0.70
mm	89	56	28	18

Design Gradation:

Location: Downstream Pebble Count

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.42	0.21	0.13	0.07
in	5.0	2.5	1.5	0.8
mm	127	64	38	20

Design Gradation:

Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				86.0
6.0	152			100	80	68	57				77.8
5.0	127			80	68	57	45				69.7
4.0	102		100	71	57	45	39				61.5
3.0	76.2		80	63	45	38	34				56.8
2.5	63.5	100	65	54	37	32	28				52.2
2.0	50.8	92.5	50	45	29	25	22				45.3
1.5	38.1	79	35	32	21	18	16				36.6
1.0	25.4	66	20	18	13	12	11				28.0
0.50	12.7	48	5	5	5	5	5				17.9
0.19	4.75	29									8.7
0.02	0.425	10									3.0
0.003	0.0750	5									1.5
% per category		30	0	0	0	70	0	0	0	0	--> 100%
% Cobble & Sediment		30.0	0.0	0.0	0.0	70.0	0.0	0.0	0.0	0.0	100.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

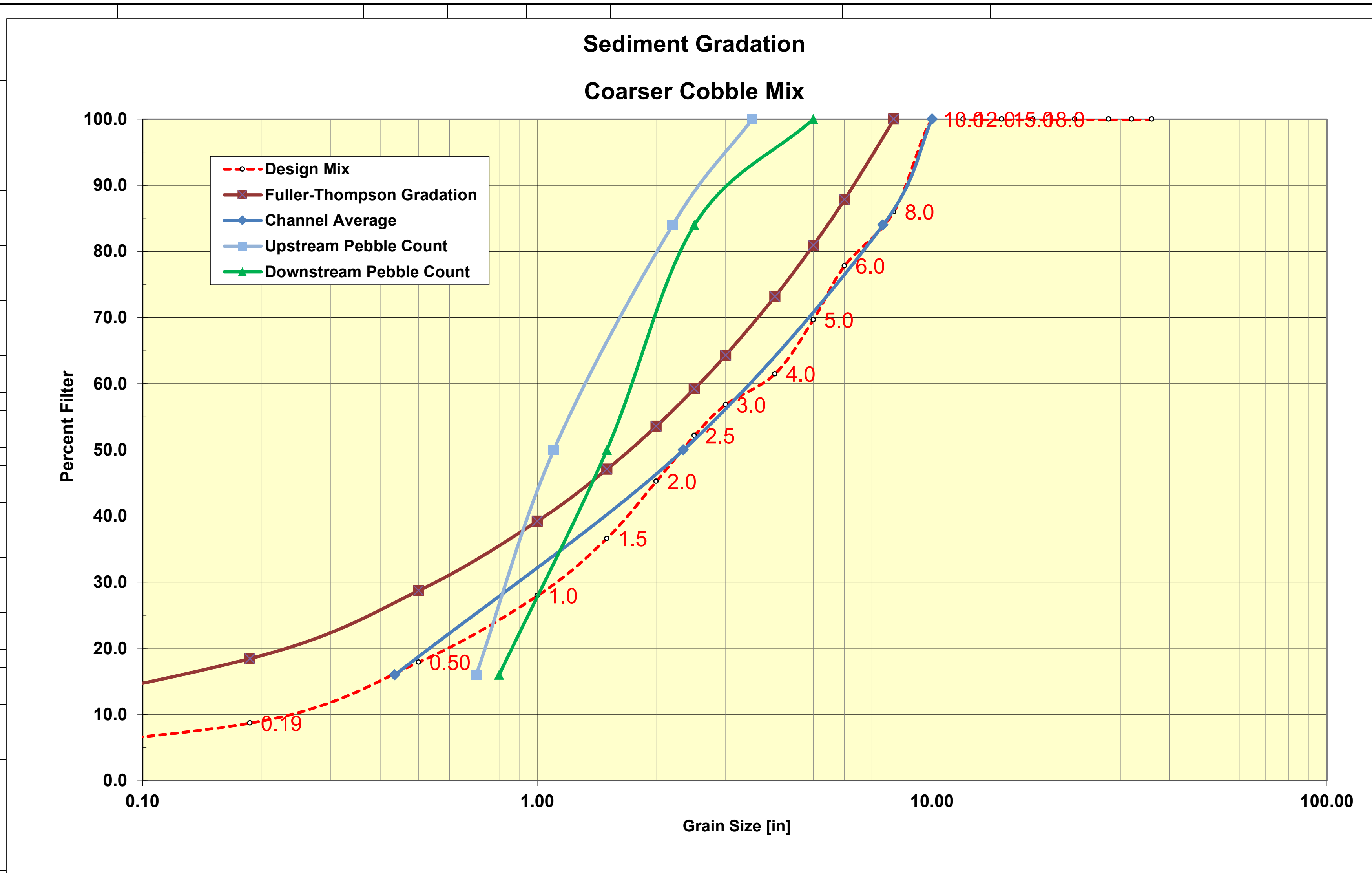
γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Average Modeled Shear Stress (lb/ft^2)	0.60	0.70	0.80	0.90	1.00	1.20

τ_{ci}	2-Year	10-Year	25-Year	50-Year	100-Year	500-Year
2.27	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.19	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.11	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.99	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.85	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.75	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.64	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.55	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.45	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.33	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.26	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.18	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
1.08	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
1.02	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
0.96	No Motion	No Motion	No Motion	No Motion	Motion	Motion
0.88	No Motion	No Motion	No Motion	Motion	Motion	Motion
0.78	No Motion	No Motion	Motion	Motion	Motion	Motion
0.63	No Motion	Motion	Motion	Motion	Motion	Motion

D50	2.34	in
	0.20	ft
	59.5	mm

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010



Fuller-Thompson Gradation	
Dmax =	8
D[in]	
12.000	120.02
10.000	110.56
8.000	100.00
6.000	87.86
5.000	80.94
4.000	73.20
3.000	64.32
2.500	59.25
2.000	53.59
1.500	47.08
1.000	39.23
0.500	28.72
0.187	18.45
0.017	6.23
0.003	2.85

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

http://www.fs.fed.us/eng/pubs/pdf/StreamSimulation/lo_res/AppendixE.pdf

Modified Shear Stress Equation:

Equation E.5

$$\tau_{ci} = \tau_{D50} (\gamma_s - \gamma) D_i^{0.3} D_{50}^{0.7}$$

where:

τ_{ci} is the critical shear stress at which the sediment particle of interest begins to move (lb/ft^2 or N/m^2).

τ_{D50} is the dimensionless Shields parameter for D_{50} particle size (this value can either be obtained from table E.1, or the value 0.045 can be used for a poorly sorted channel bed).

D_{50} is the diameter (ft or m) of the median or 50th percentile particle size of the channel bed .

D_i is the diameter (ft or m) of the particle size of interest. For stream simulation the particle size of interest is typically D_{84} and/or D_{95}.

Assuming γ_s = 165 lb/ft^3 and γ = 62.4 lb/ft^3, equation 5 can be simplified to:

Equation E.6

$$\tau_{ci} = 102.6\ \tau_{D50}\ D_i^{\ 0.3}\ D_{50}^{\ 0.7}$$

Table E.1—Shield's parameter for different particle sizes. Modified from Julien 1995

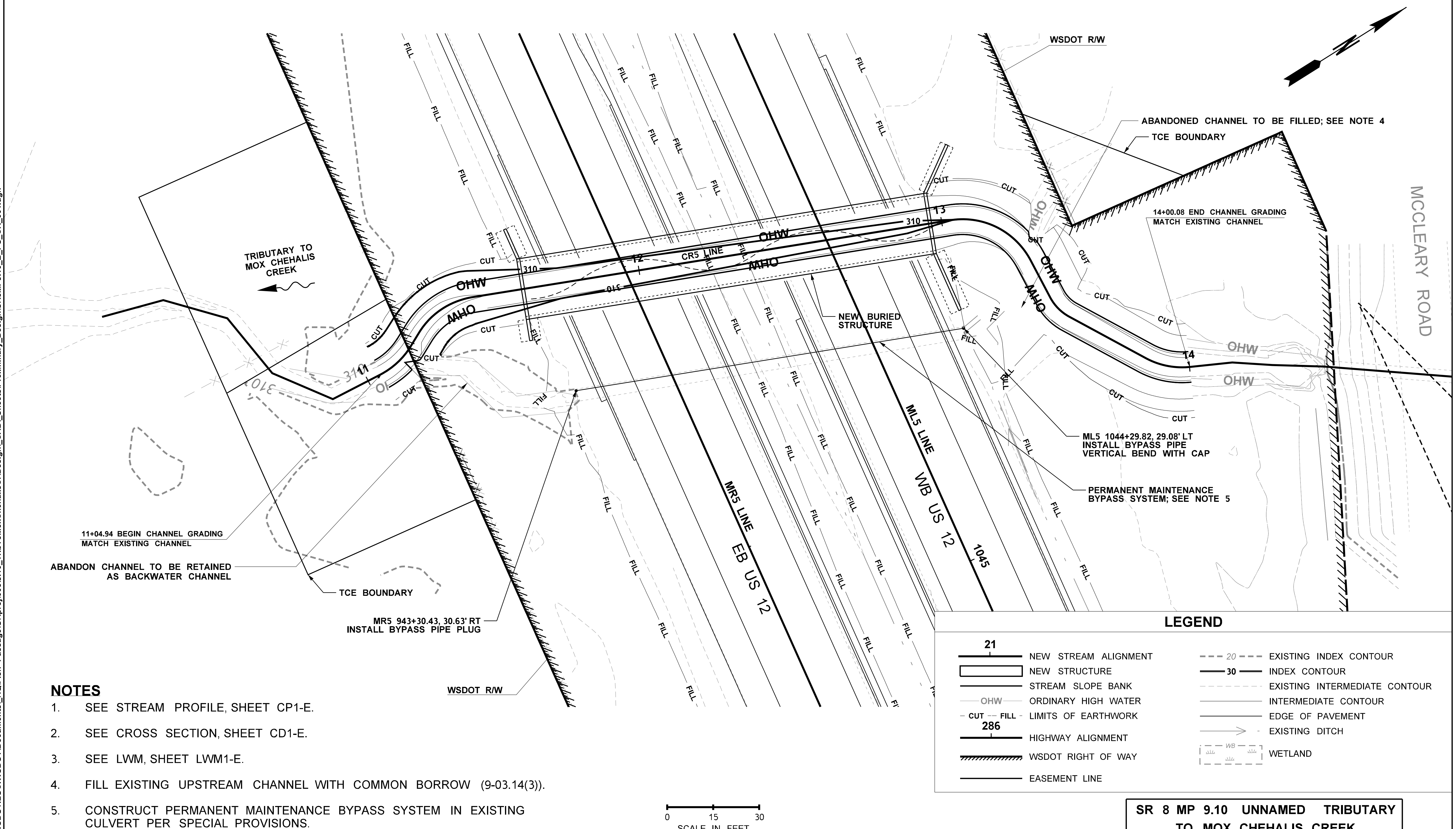
Particle size classification	Particle size, D (mm)	Angle of repose, ϕ (degrees)	Shield's parameter, τ^*	Critical shear stress, τ_c (lb/ft^2)
very large boulders	> 2,048	42	0.054	37.37
large boulders	1,024-2,048	42	0.054	18.68
medium boulders	512-1,024	42	0.054	9.34
small boulders	256-512	42	0.054	4.67
large cobbles	128-256	42	0.054	2.34
small cobbles	64-128	41	0.052	1.13
very coarse gravels	32-64	40	0.050	0.54
coarse gravels	16-32	38	0.047	0.25
medium gravels	8-16	36	0.044	0.12
fine gravels	4-8	35	0.042	0.057
very fine gravels	2-4	33	0.039	0.026

The equation used to determine the Shields parameter for gravels, cobbles, and boulders is $\tau^* = 0.06 \tan\phi$.

The Shield's parameter and critical shear stress values are for the smallest

The Shield's parameter and critical shear stress values are for the smallest number in the particle-size interval.

Appendix D: Stream Plan Sheets, Profile, Details



LEGEND

NEW STREAM ALIGNMENT	EXISTING INDEX CONTOUR
NEW STRUCTURE	INDEX CONTOUR
STREAM SLOPE BANK	EXISTING INTERMEDIATE CONTOUR
ORDINARY HIGH WATER	INTERMEDIATE CONTOUR
LIMITS OF EARTHWORK	EDGE OF PAVEMENT
HIGHWAY ALIGNMENT	EXISTING DITCH
WSDOT RIGHT OF WAY	WETLAND
EASEMENT LINE	

NOTES

1. SEE STREAM PROFILE, SHEET CP1-E.
2. SEE CROSS SECTION, SHEET CD1-E.
3. SEE LWM, SHEET LWM1-E.
4. FILL EXISTING UPSTREAM CHANNEL WITH COMMON BORROW (9-03.14(3)).
5. CONSTRUCT PERMANENT MAINTENANCE BYPASS SYSTEM IN EXISTING CULVERT PER SPECIAL PROVISIONS.

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354365\SR8MP9.10_B_PS_CR_001.dgn
TIME	10:02:05 AM
DATE	10/18/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE | P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

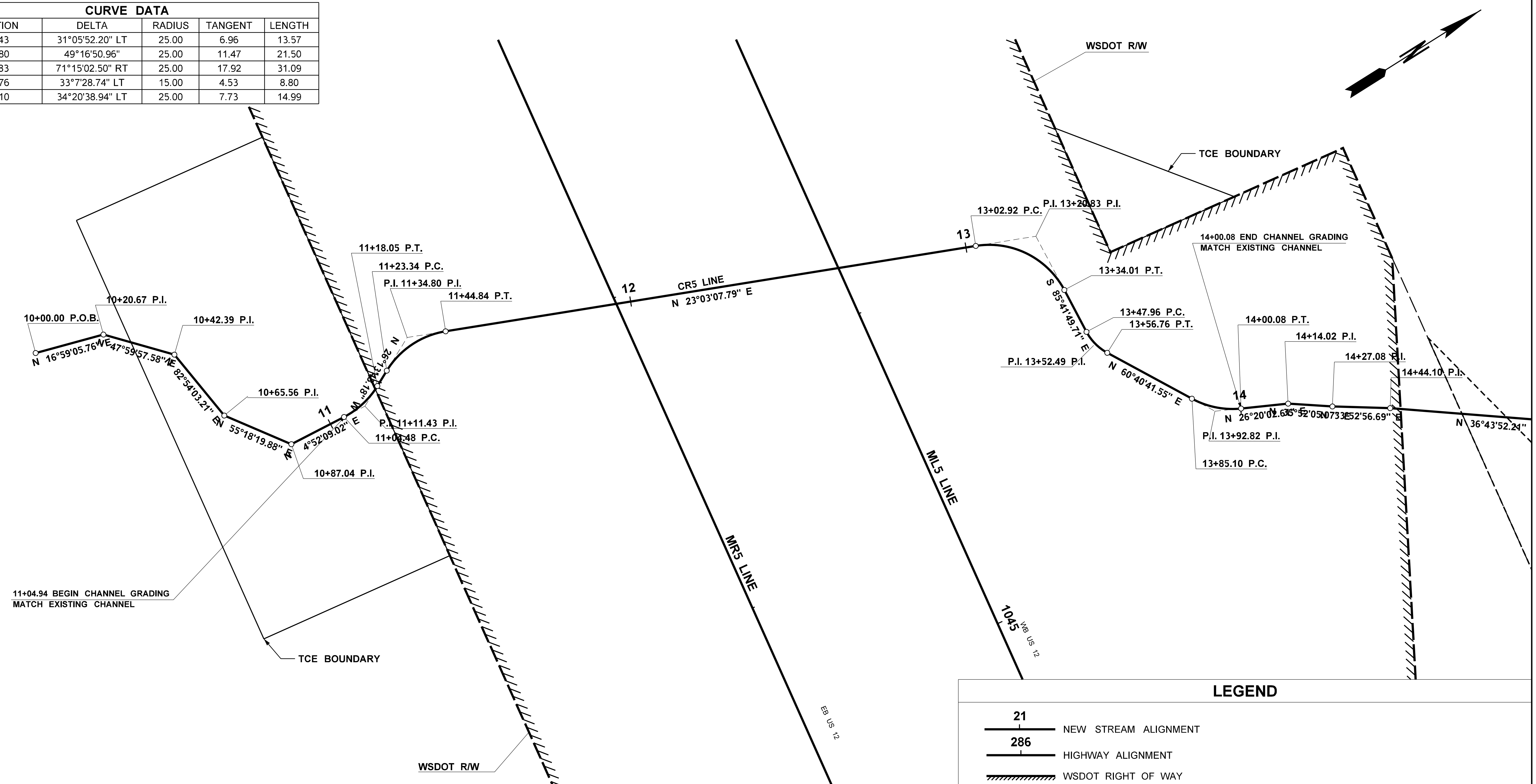
STREAM PLAN

PLAN REF NO CR1-E

SHEET OF SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\9.10_TribToMoxChehalisCr\Design_CAD_Sheets\Preliminary_Design\SR8MP9.10_B_PS_CR_001.dgn

CURVE DATA				
P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH
11+11.43	31°05'52.20" LT	25.00	6.96	13.57
11+34.80	49°16'50.96"	25.00	11.47	21.50
13+20.83	71°15'02.50" RT	25.00	17.92	31.09
13+56.76	33°7'28.74" LT	15.00	4.53	8.80
13+85.10	34°20'38.94" LT	25.00	7.73	14.99



NOTES

1. SEE STREAM PROFILE, SHEET CP1-E.
2. SEE CROSS SECTION, SHEET CD1-E.
3. SEE LWM, SHEET LWM1-E.

0 15 30
SCALE IN FEET

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354365\SR8MP9.10_B_PS_CR_002.dgn
TIME	10:02:07 AM
DATE	10/18/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	D. HENNING
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	J. WYNANDS

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER
CONTRACT NO. | LOCATION NO. XL6115

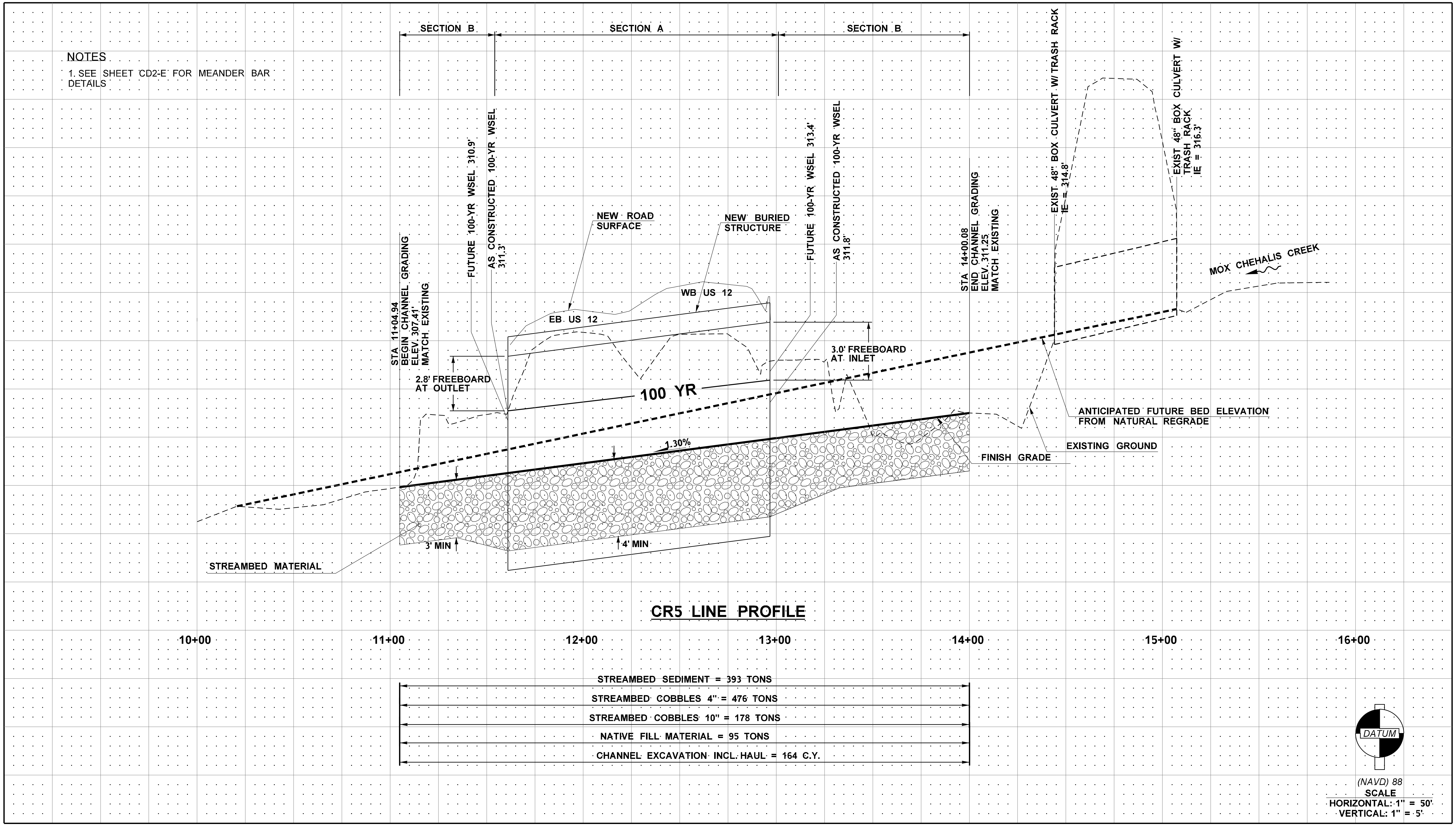
P.E. STAMP BOX DATE
P.E. STAMP BOX DATE

Washington State Department of Transportation
DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PLAN

PLAN REF NO CR2-E
SHEET OF SHEETS



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SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

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PLOTTED BY	Rhw				
DESIGNED BY	K. COMINGS				
ENTERED BY	R. WILCOX				
CHECKED BY	J. GAGE				
PROJ. ENGR.	B. ELLIOTT				
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY	

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

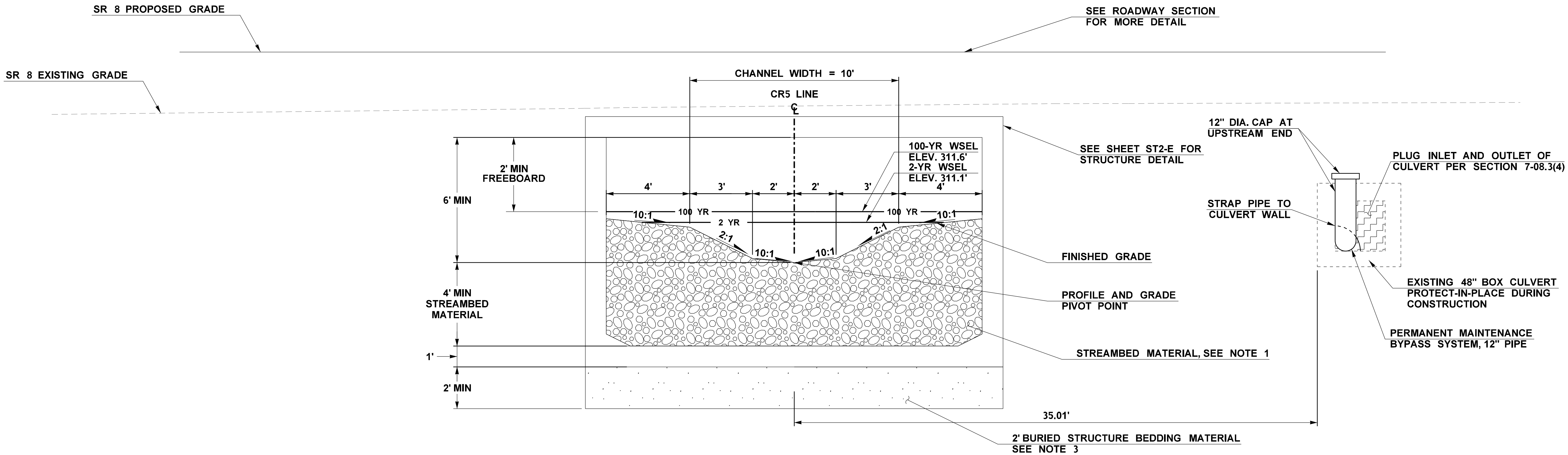
STREAM PROFILE

PLAN REF. NO. CP1-E

SHEET

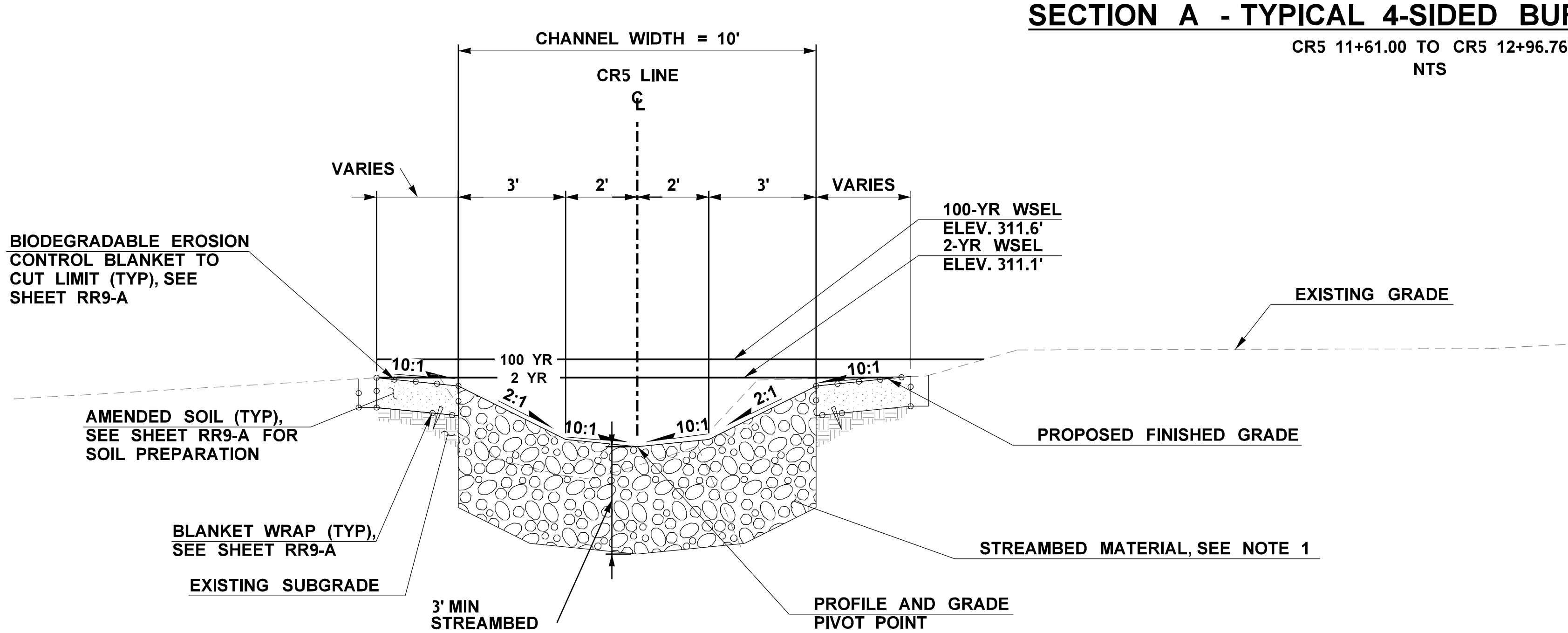
OF

SHEETS



SECTION A - TYPICAL 4-SIDED BURIED STRUCTURE

CR5 11+61.00 TO CR5 12+96.76
NTS



SECTION A - TYPICAL OPEN CHANNEL

CR5 11+04.94 TO CR5 11+61.00
CR5 12+96.76 TO CR5 14+00.08
NTS

NOTES

1. STREAMBED MATERIAL SHALL CONSIST OF A WELL GRADED MIX OF 60 PERCENT 4" STREAMBED COBBLES (9-03.11(2)) AND 40 PERCENT STREAMBED SEDIMENT (9-03.11(1)).
2. A 2' MINIMUM FREEBOARD IS REQUIRED ABOVE THE 100-YEAR FLOOD WSE.
3. SEE STRUCTURAL PLAN, SHEET ST2-E FOR BURIED STRUCTURE BEDDING MATERIAL.

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

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TIME	10:02:10 AM
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DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

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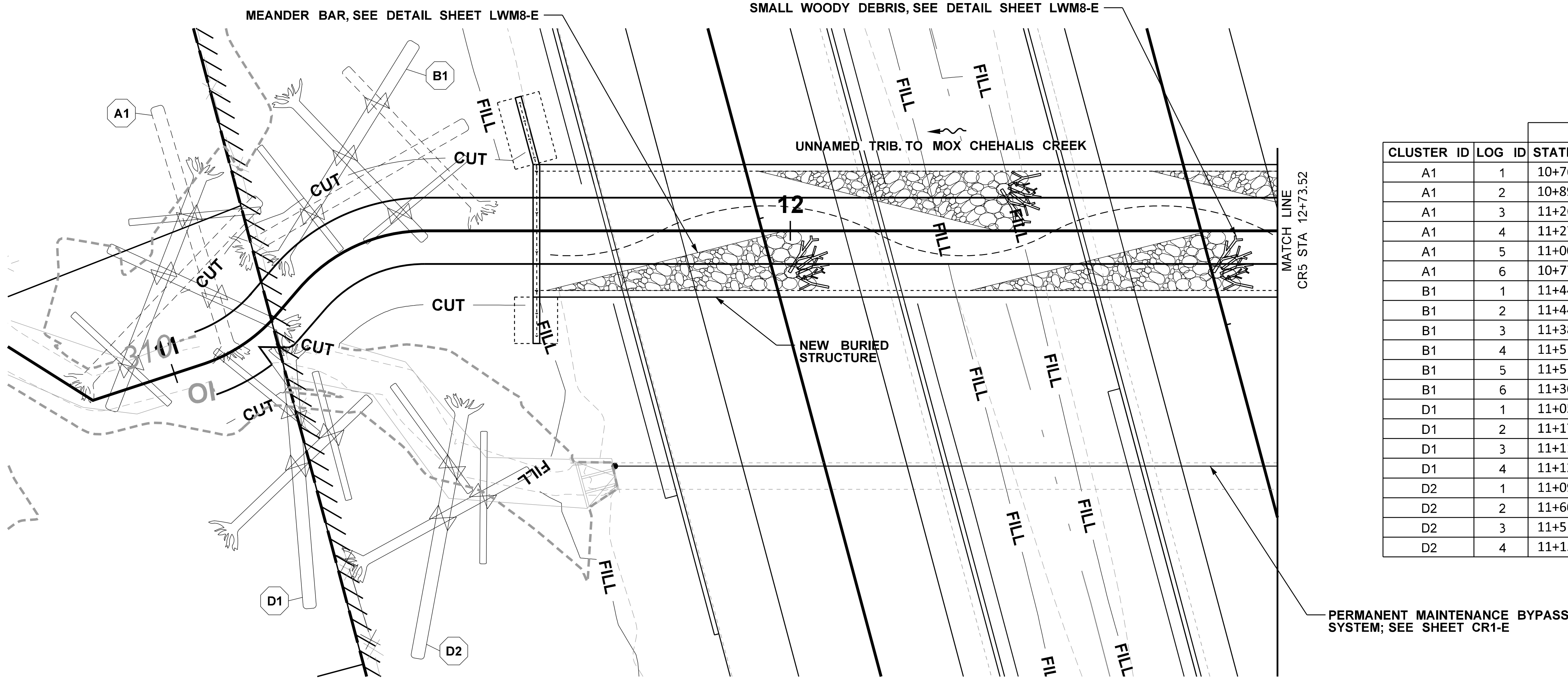
Washington State Department of Transportation
DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM DETAILS

PLAN REF NO CD1-E
SHEET OF SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\9.10_TribToMoxChehalisCr\Design_CAD_Sheets\Preliminary_Design\SR8MP9.10_B_DE_CR_001.dgn



LARGE WOODY MATERIAL - DOWNSTREAM END

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
A1	1	10+76.7	20.7' LT	11+17.2	1.9' RT	SEE SHEET LWM3-E
A1	2	10+89.4	2.3' RT	10+25.0	22.3' LT	SEE SHEET LWM3-E
A1	3	11+26.2	34.6' LT	11+09.3	0.6' LT	SEE SHEET LWM3-E
A1	4	11+27.5	14.0' LT	10+84.8	2.2' LT	SEE SHEET LWM3-E
A1	5	11+00.6	23.9' LT	11+26.8	12.4' LT	SEE SHEET LWM3-E
A1	6	10+77.5	9.4' LT	10+97.9	4.2' RT	SEE SHEET LWM3-E
B1	1	11+44.9	1.3' RT	11+34.4	23.6' LT	SEE SHEET LWM4-E
B1	2	11+44.2	28.4' LT	11+25.6	5.3' LT	SEE SHEET LWM4-E
B1	3	11+38.9	25.8' LT	11+52.8	3.5' LT	SEE SHEET LWM4-E
B1	4	11+51.1	16.5' LT	11+23.1	9.7' LT	SEE SHEET LWM4-E
B1	5	11+51.2	11.1' LT	11+35.6	0.1' LT	SEE SHEET LWM4-E
B1	6	11+30.2	20.2' LT	11+31.8	0.3' LT	SEE SHEET LWM4-E
D1	1	11+05.9	40.3' RT	11+15.3	6.0' RT	SEE SHEET LWM6-E
D1	2	11+17.8	18.8' RT	11+01.3	24.8' RT	SEE SHEET LWM6-E
D1	3	11+11.4	28.3' RT	11+06.1	10.0' RT	SEE SHEET LWM6-E
D1	4	11+12.4	17.5' RT	11+07.0	1.2' LT	SEE SHEET LWM6-E
D2	1	11+09.9	54.3' RT	11+50.6	27.2' RT	SEE SHEET LWM6-E
D2	2	11+60.7	36.1' RT	11+10.1	37.3' RT	SEE SHEET LWM6-E
D2	3	11+51.7	39.5' RT	11+21.4	20.2' RT	SEE SHEET LWM6-E
D2	4	11+15.3	48.4' RT	11+53.7	29.9' RT	SEE SHEET LWM6-E

BOLE END

ROOTWAD END

0 10 20
SCALE IN FEET

LEGEND

21	NEW STREAM ALIGNMENT
	NEW STRUCTURE
	STREAM SLOPE BANK
OHW	ORDINARY HIGH WATER
CUT -- FILL	LIMITS OF EARTHWORK
286	HIGHWAY ALIGNMENT
	WSDOT RIGHT OF WAY
	EASEMENT LINE
20	EXISTING INDEX CONTOUR
30	INDEX CONTOUR
	EXISTING INTERMEDIATE CONTOUR
	INTERMEDIATE CONTOUR
	EDGE OF PAVEMENT

NOTES:

1. DASHED LINES INDICATE BURIED LOGS.
2. SEE SHEETS LWM3-E, LWM4-E, LWM5-E, AND LWM6-E FOR LOG ID NUMBERS.
3. LOCATIONS AND ORIENTATIONS OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE DIRECTED BY THE ENGINEER IN THE FIELD. SEE SPECIAL PROVISION "LARGE WOODY MATERIAL (LWM) STRUCTURES".
4. 100-YR WSEL: 314.5'

LEGEND

- 24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD (7 TOTAL)
- 18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD (5 TOTAL)
- 12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD (8 TOTAL)
- CABLE LASHING, SEE SHEET LWM7-E
- CLUSTER ID, SEE SHEETS LWM3-E, LWM4-E, LWM5-E, AND LWM6-E — (x)

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354365\SR8MP9.10_B_PS_LWM_001.dgn
TIME	10:02:14 AM
DATE	10/18/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001
JOB NUMBER 21C522
CONTRACT NO. XL6115
LOCATION NO.

P.E. STAMP BOX — DATE
P.E. STAMP BOX — DATE

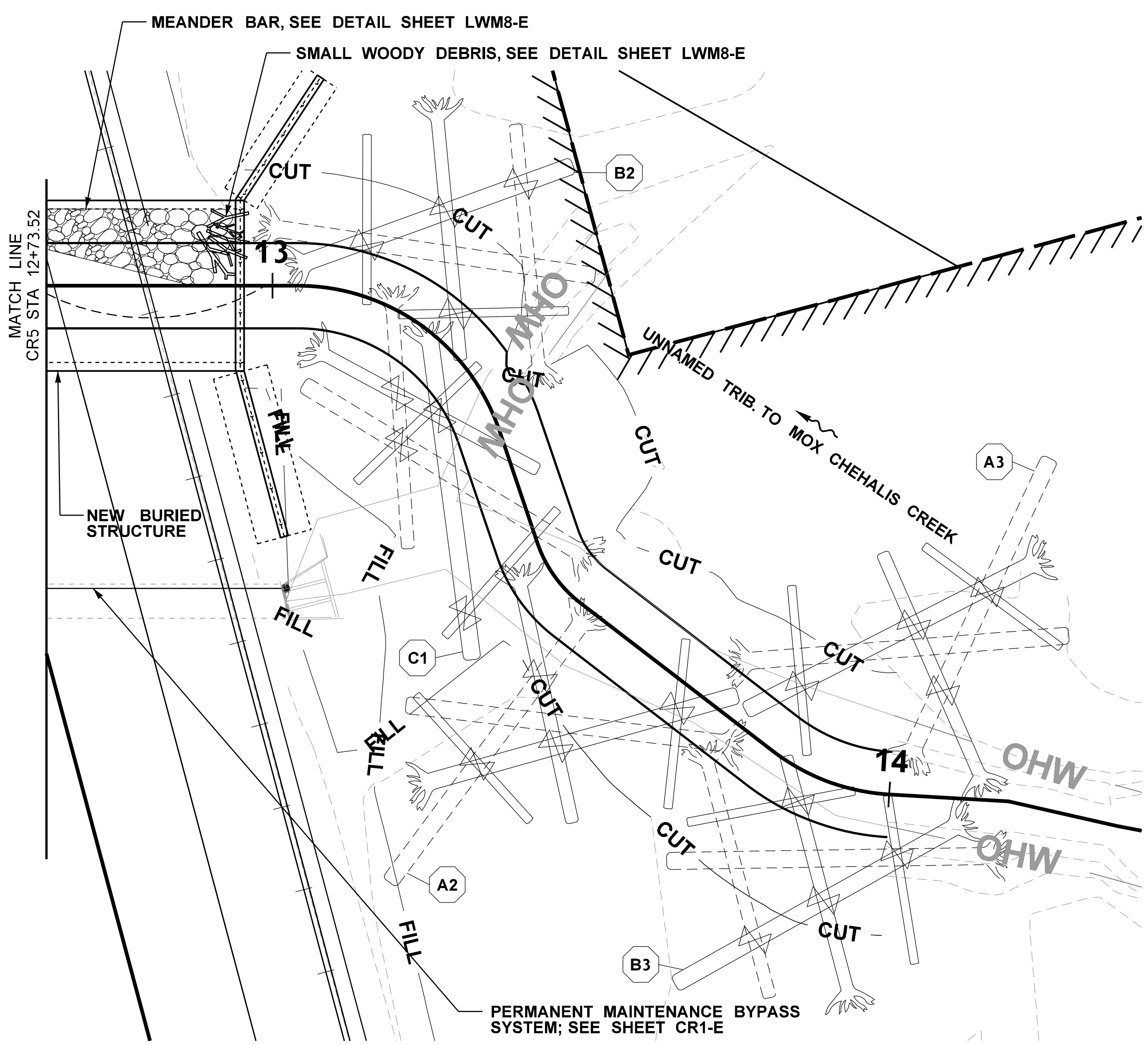
Washington State Department of Transportation
DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL PLAN

PLAN REF NO LWM1-E
SHEET OF SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\9.10_TribToMoxChehalisCr\Design_CAD_Sheets\Preliminary_Design\SR8MP9.10_B_PS_LWM_001.dgn



LARGE WOODY MATERIAL - UPSTREAM END

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
B2	1	13+24.5	0.1' LT	13+11.8	22.9' LT	SEE SHEET LWM4-E
B2	2	13+20.2	25.7' LT	13+03.9	2.9' LT	SEE SHEET LWM4-E, TRIM TO FIT WITHIN ROW
B2	3	13+16.1	25.9' LT	13+29.9	6.9' LT	SEE SHEET LWM4-E
B2	4	13+26.1	18.9' LT	13+00.9	6.6' LT	SEE SHEET LWM4-E
B2	5	13+27.1	13.6' LT	13+15.2	0.3' RT	SEE SHEET LWM4-E
B2	6	13+07.7	18.5' LT	13+11.4	0.8' RT	SEE SHEET LWM4-E
C1	1	13+53.6	13.6' RT	13+20.4	0.7' RT	SEE SHEET LWM5-E
C1	2	13+99.9	2.9' LT	13+07.4	7.5' RT	SEE SHEET LWM5-E
C1	3	13+43.9	14.7' RT	13+14.2	0.2' LT	SEE SHEET LWM5-E
C1	4	13+04.4	11.5' RT	13+51.5	4.3' LT	SEE SHEET LWM5-E
C1	5	13+34.4	17.9' RT	13+26.3	1.7' LT	SEE SHEET LWM5-E
C1	6	13+51.6	14.8' RT	13+44.8	3.7' LT	SEE SHEET LWM5-E
A2	1	13+71.8	21.0' RT	13+51.1	3.7' RT	SEE SHEET LWM3-E
A2	2	13+78.0	2.7' LT	13+56.4	27.4' RT	SEE SHEET LWM3-E
A2	3	13+59.0	39.7' RT	13+58.3	1.8' RT	SEE SHEET LWM3-E
A2	4	13+53.2	23.1' RT	13+80.4	2.4' RT	SEE SHEET LWM3-E
A2	5	13+67.7	24.0' RT	13+53.1	21.4' RT	SEE SHEET LWM3-E
A2	6	13+79.6	12.8' RT	13+69.0	4.3' LT	SEE SHEET LWM3-E
B3	1	13+86.8	0.5' LT	13+98.4	23.5' RT	SEE SHEET LWM4-E
B3	2	13+88.7	29.3' RT	14+08.2	3.2' RT	SEE SHEET LWM4-E
B3	3	13+93.8	26.2' RT	13+80.0	5.4' RT	SEE SHEET LWM4-E
B3	4	13+83.2	17.8' RT	14+12.3	6.5' RT	SEE SHEET LWM4-E
B3	5	13+82.2	12.7' RT	13+96.0	0.1' RT	SEE SHEET LWM4-E
B3	6	14+04.1	19.6' RT	13+99.8	0.1' RT	SEE SHEET LWM4-E
A3	1	13+81.2	26.3' LT	14+10.5	2.5' LT	SEE SHEET LWM3-E
A3	2	13+79.9	1.7' LT	14+14.5	27.6' LT	SEE SHEET LWM3-E
A3	3	14+16.2	39.3' LT	14+02.5	5.3' LT	SEE SHEET LWM3-E
A3	4	14+16.6	20.6' LT	13+76.3	6.5' LT	SEE SHEET LWM3-E
A3	5	14+02.4	29.4' LT	14+16.0	19.0' LT	SEE SHEET LWM3-E
A3	6	13+75.1	16.8' LT	13+89.1	1.7' LT	SEE SHEET LWM3-E

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD (12 TOTAL)	
18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD (8 TOTAL)	
12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD (10 TOTAL)	
CABLE LASHING, SEE SHEET LWM7-E	
CLUSTER ID, SEE SHEETS LWM3-E, LWM4-E, LWM5-E, AND LWM6-E	x

LEGEND

21	NEW STREAM ALIGNMENT	20	EXISTING INDEX CONTOUR
	NEW STRUCTURE	30	INDEX CONTOUR
	STREAM SLOPE BANK		EXISTING INTERMEDIATE CONTOUR
OHW	ORDINARY HIGH WATER		INTERMEDIATE CONTOUR
CUT — FILL	LIMITS OF EARTHWORK		EDGE OF PAVEMENT
286	HIGHWAY ALIGNMENT		
	WSDOT RIGHT OF WAY		
	EASEMENT LINE		

NOTES:

1. DASHED LINES INDICATE BURIED LOGS.
2. SEE SHEETS LWM3-E, LWM4-E, LWM5-E, AND LWM6-E FOR LOG ID NUMBERS.
3. LOCATIONS AND ORIENTATIONS OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE DIRECTED BY THE ENGINEER IN THE FIELD. SEE SPECIAL PROVISION "LARGE WOODY MATERIAL (LWM) STRUCTURES".
4. 100-YR WSEL: 314.5'

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

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DATE	10/18/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001
JOB NUMBER 21C522
CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX | DATE
P.E. STAMP BOX | DATE

Washington State Department of Transportation
DAVID EVANS AND ASSOCIATES INC.

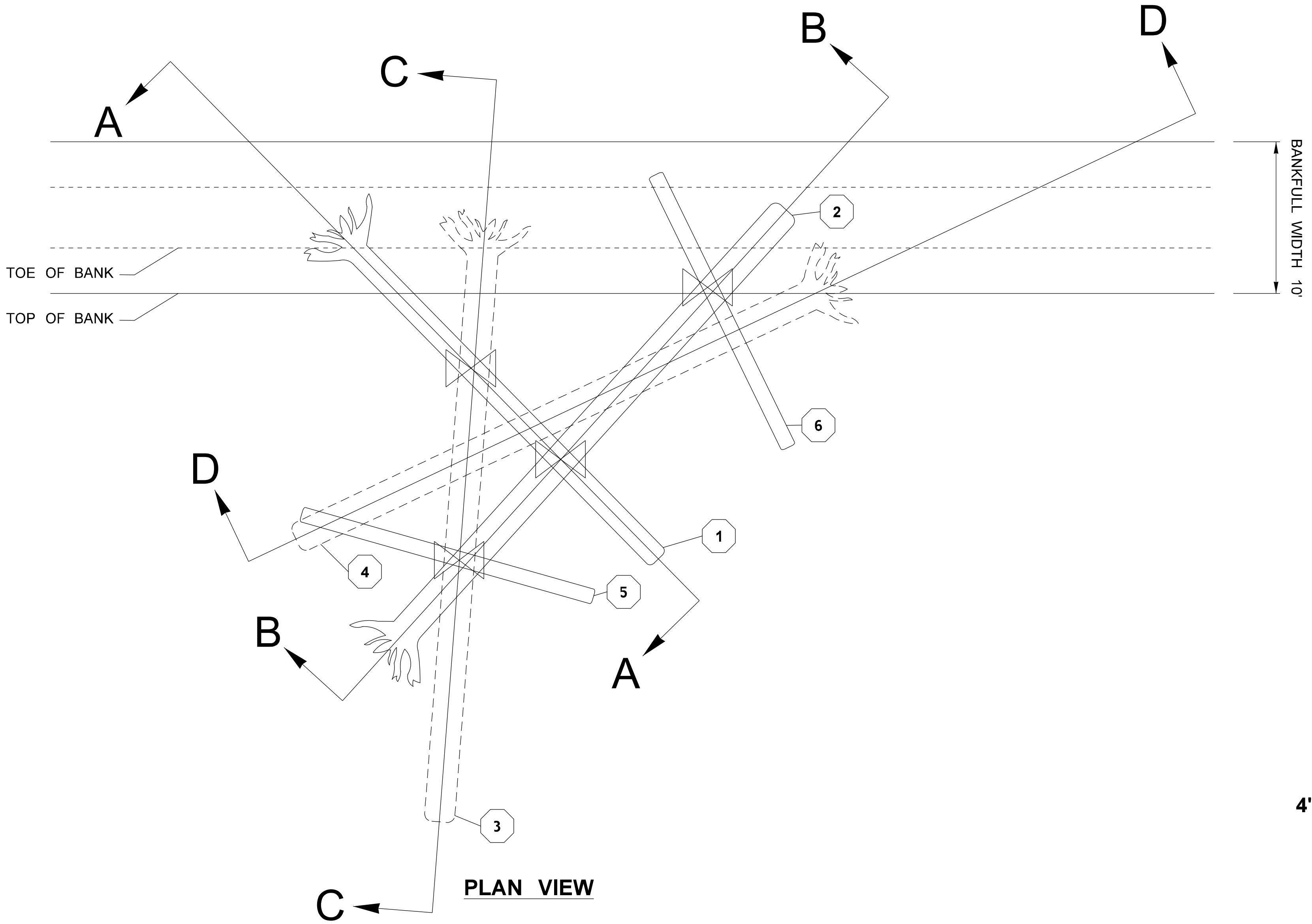
US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL PLAN

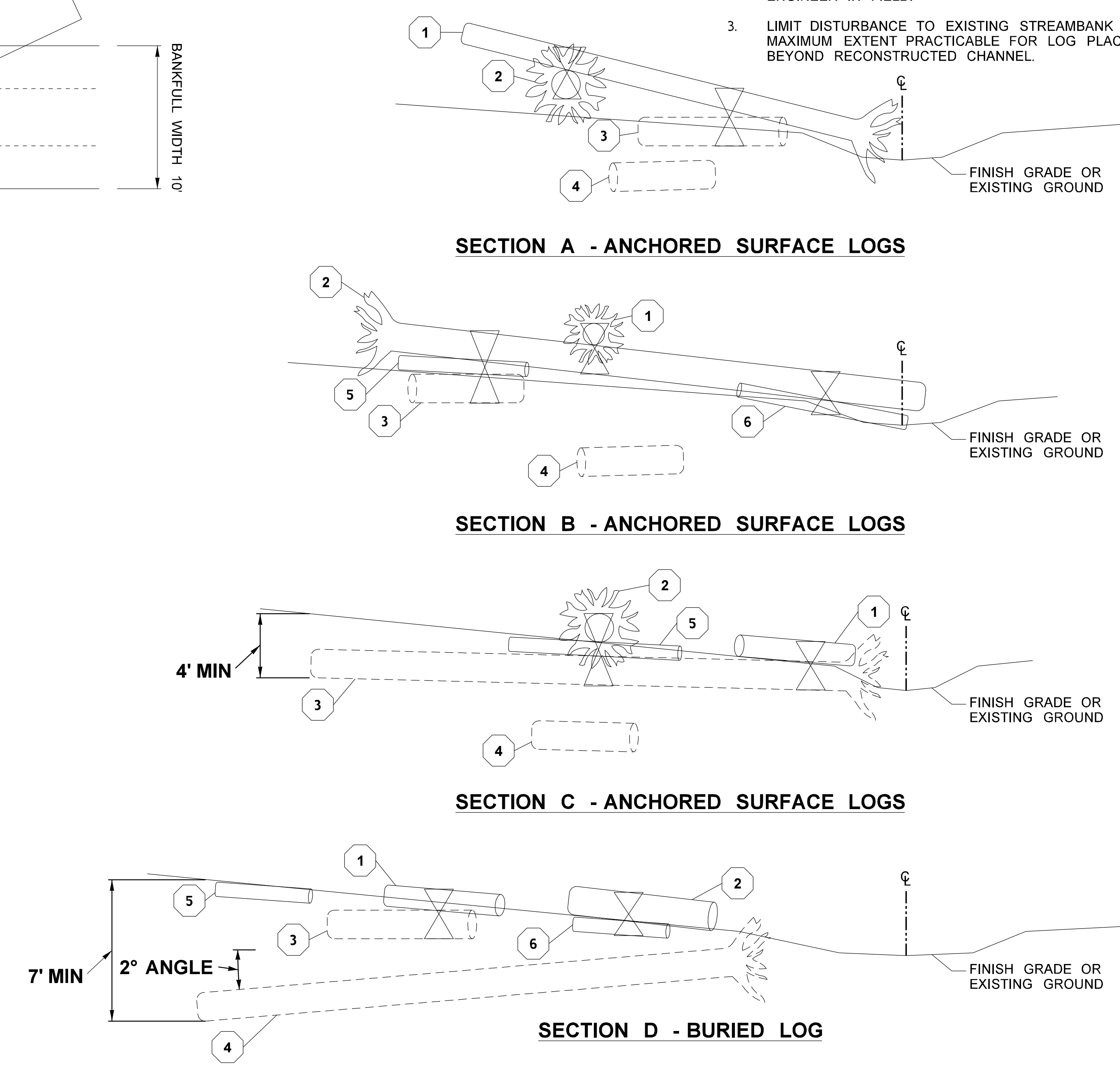
PLAN REF NO LWM2-E
SHEET
OF
SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\00819.10_TribToMoxChehalisCr\Design_CAD_Sheets\Preliminary_Design\SR8MP9.10_B_PS_LWM_002.dgn

NOTES:
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



PLAN VIEW



SECTION A - ANCHORED SURFACE LOGS

SECTION B - ANCHORED SURFACE LOGS

SECTION C - ANCHORED SURFACE LOGS

SECTION D - BURIED LOG

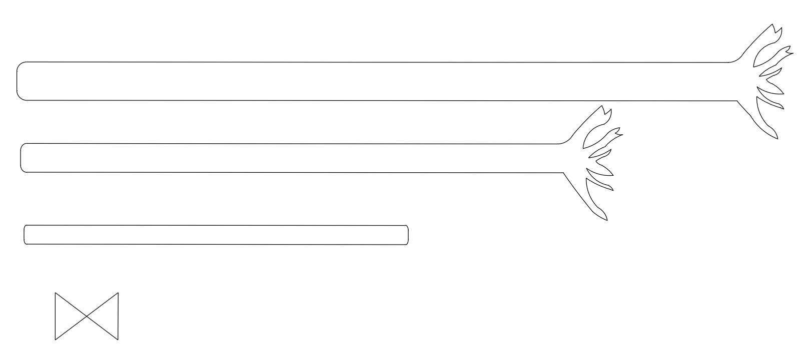
LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD

CABLE LASHING, SEE SHEET LWM7-E



LARGE WOOD CLUSTER TYPE A

NTS

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TIME	10:02:20 AM
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DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
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PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

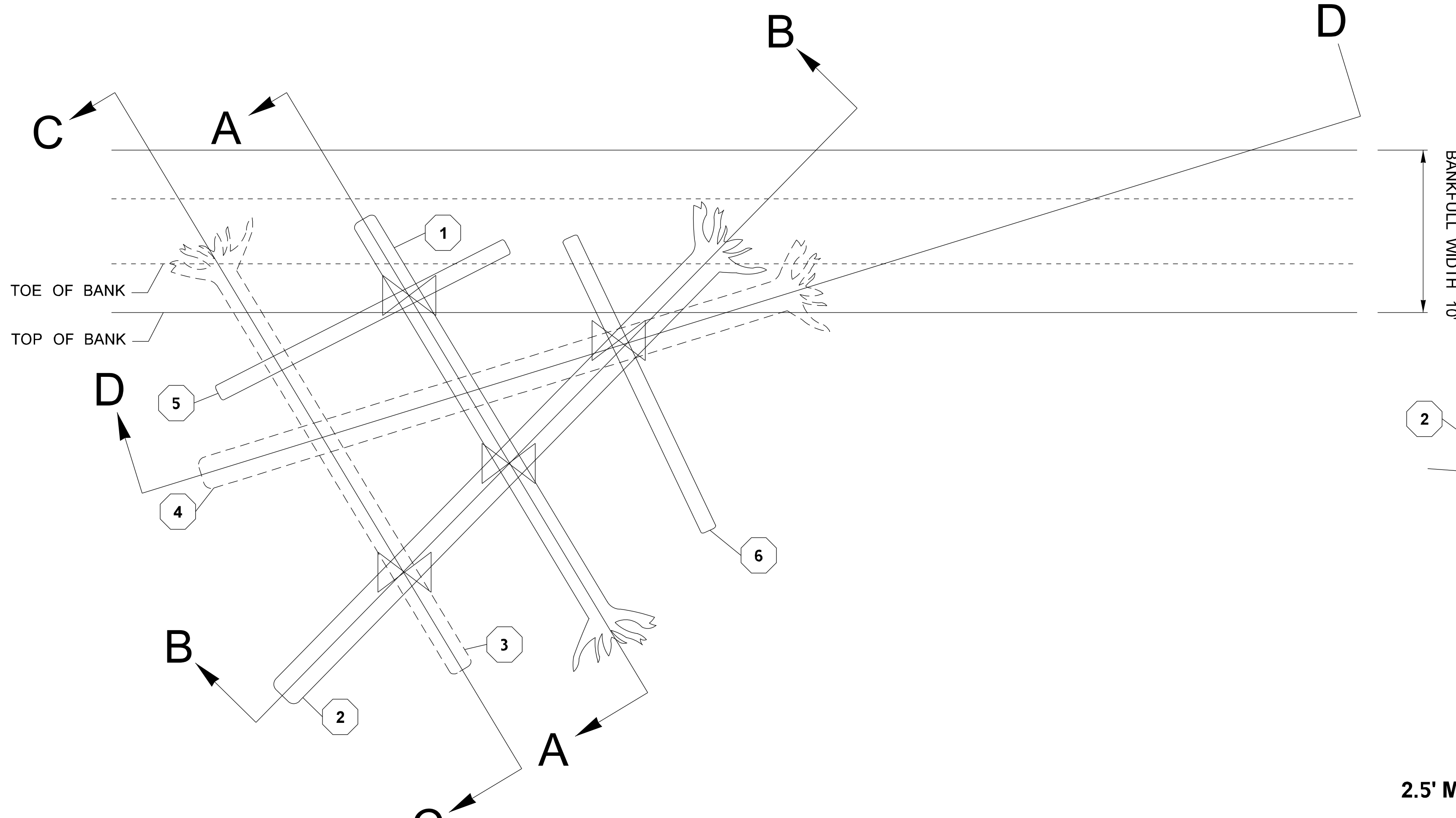
LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM3-E

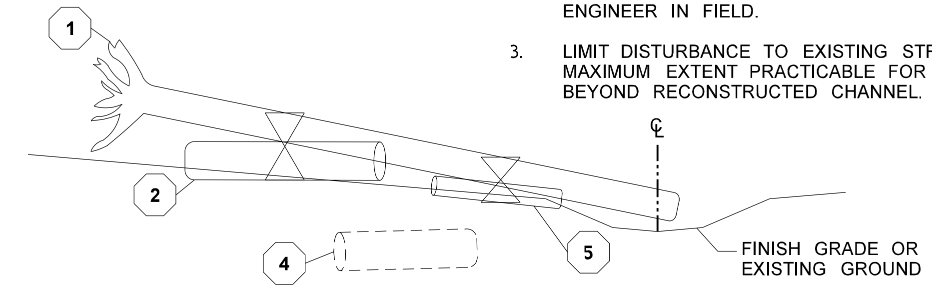
SHEET OF SHEETS

NOTES:

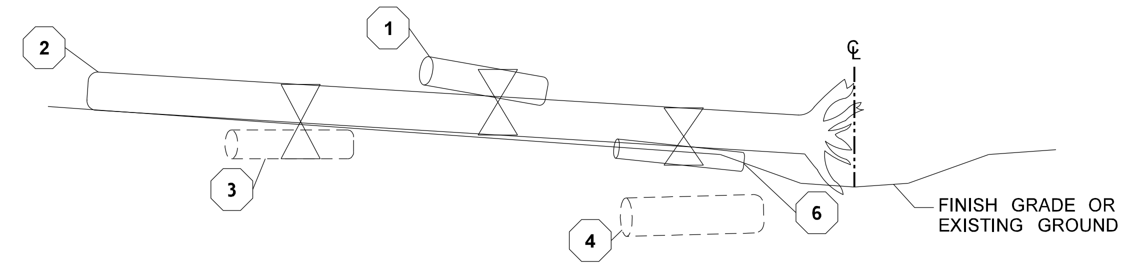
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



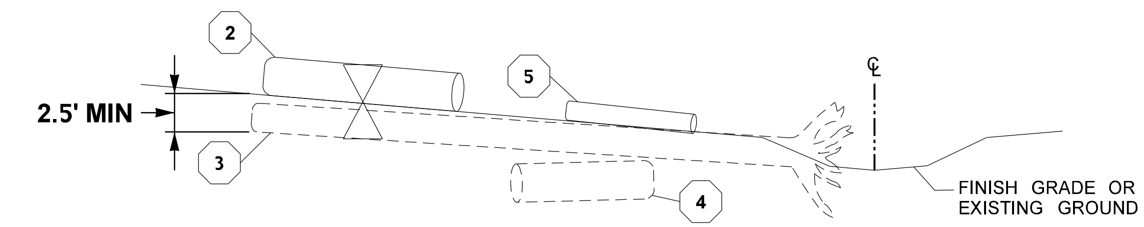
PLAN VIEW



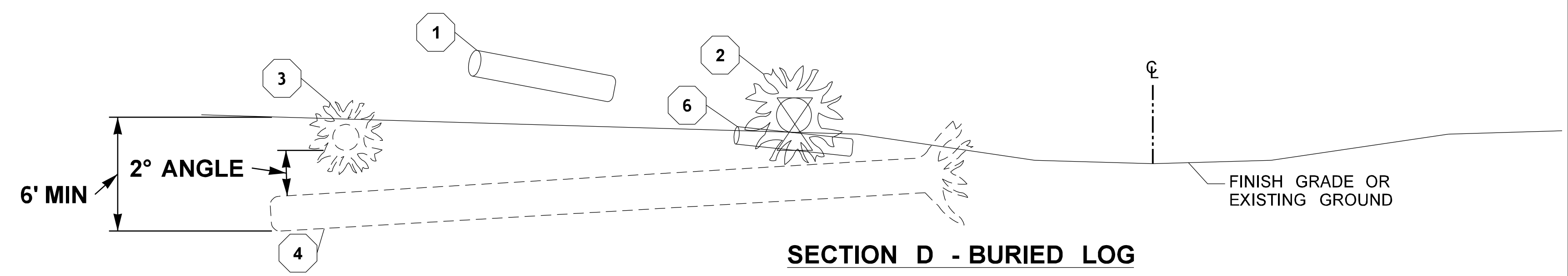
SECTION A - ANCHORED SURFACE LOGS



SECTION B - ANCHORED SURFACE LOGS

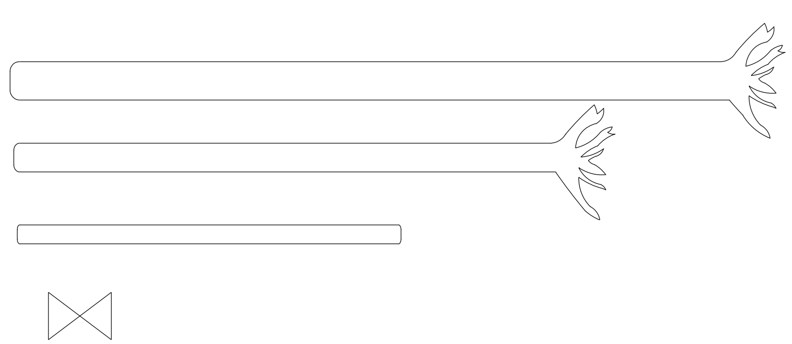


SECTION C - ANCHORED SURFACE LOGS



SECTION D - BURIED LOG

LEGEND



24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD

CABLE LASHING, SEE SHEET LWM7-E

LARGE WOOD CLUSTER TYPE B

NTS

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

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DATE	10/18/2022				
PLOTTED BY	Rhw				
DESIGNED BY	K. COMINGS				
ENTERED BY	R. WILCOX				
CHECKED BY	J. GAGE				
PROJ. ENGR.	B. ELLIOTT				
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY	

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

P.E. STAMP BOX — DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

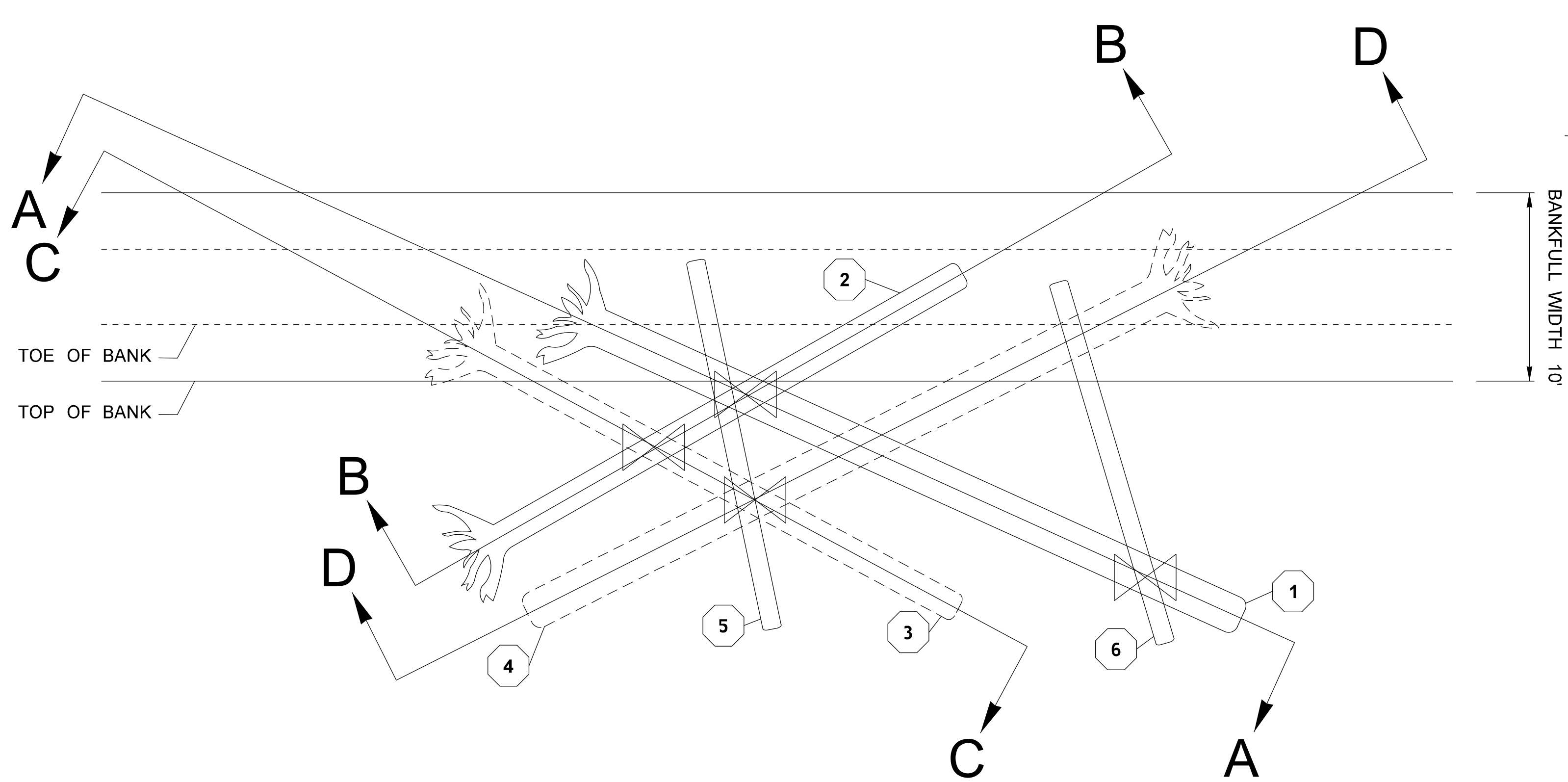
LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM4-E

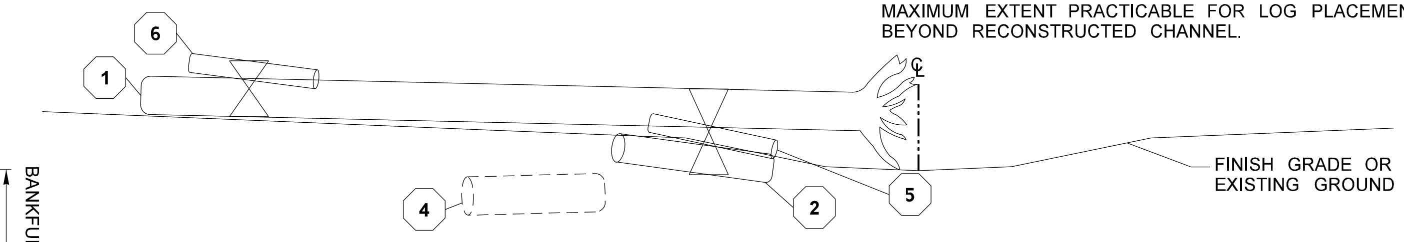
SHEET OF SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\9.10_TribToMoxChehalisCr\Design_CAD_Sheets\Preliminary_Design\SR8MP9.10_B_DE_LWM_002.dgn

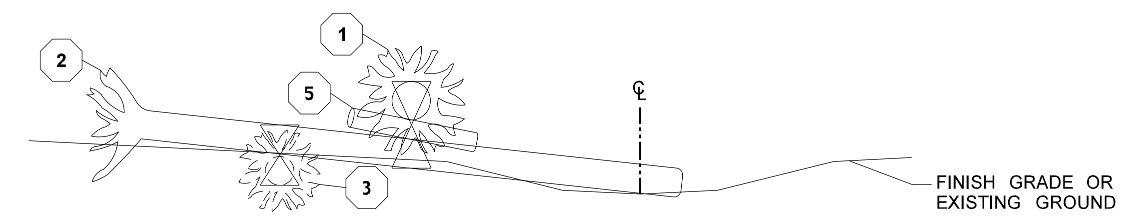
NOTES:
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



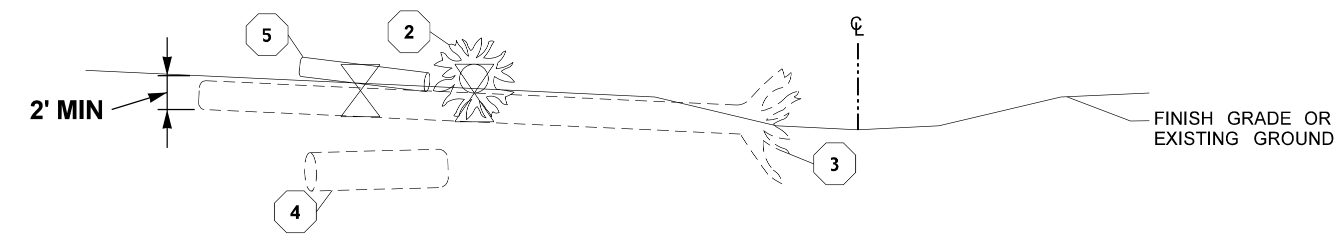
PLAN VIEW



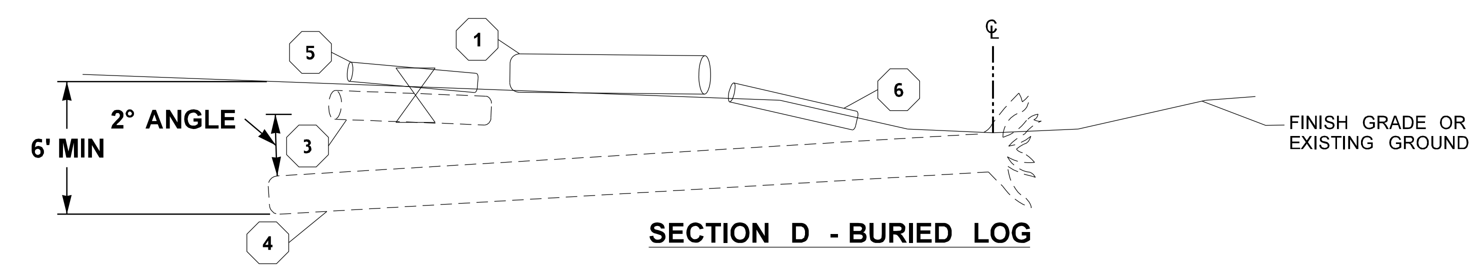
SECTION A - ANCHORED SURFACE LOGS



SECTION B - ANCHORED SURFACE LOGS



SECTION C - ANCHORED SURFACE LOGS



SECTION D - BURIED LOG

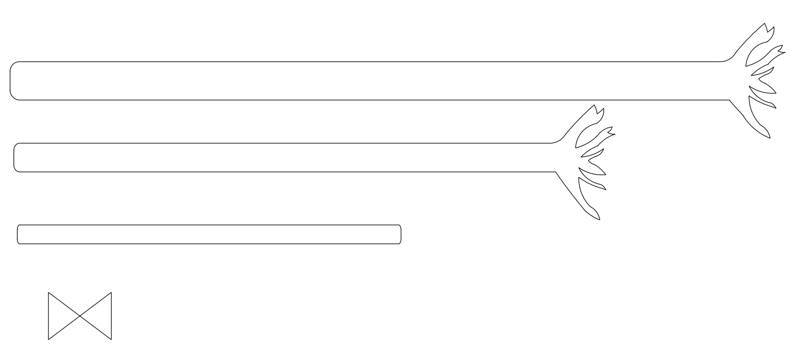
LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD

CABLE LASHING, SEE SHEET LWM7-E



LARGE WOOD CLUSTER TYPE C

NTS

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

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DATE	10/18/2022			
PLOTTED BY	Rhw			
DESIGNED BY	K. COMINGS			
ENTERED BY	R. WILCOX			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

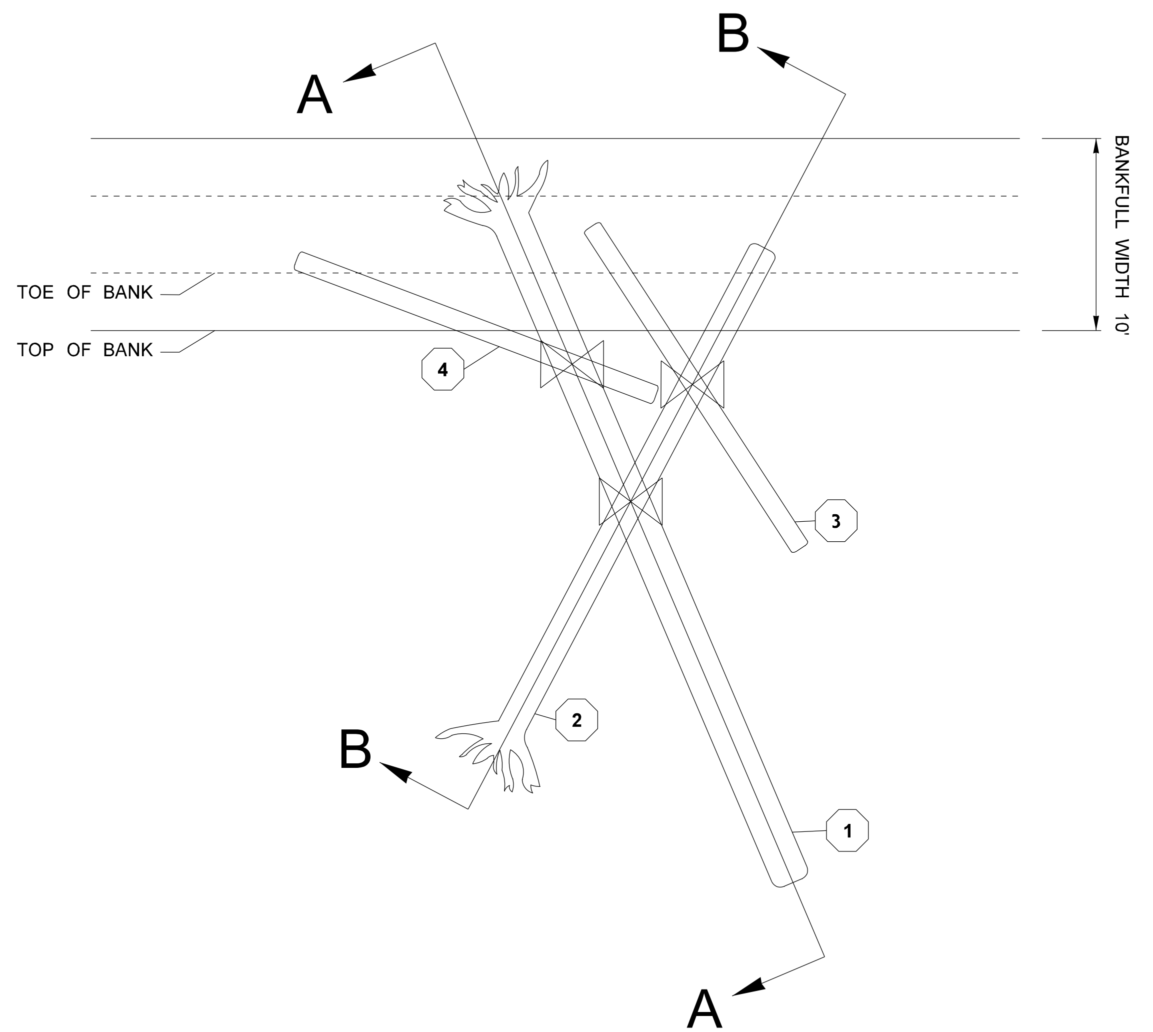
PLAN REF NO LWM5-E

SHEET OF SHEETS

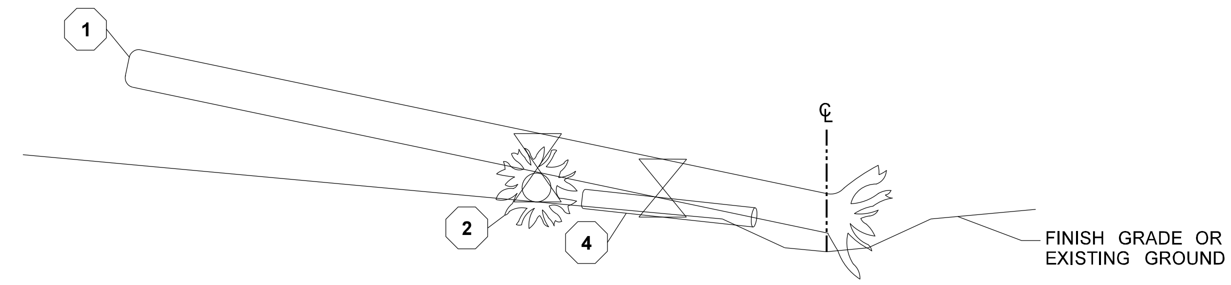
pw:\\HQOLYMAPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\9.10_TribToMoxChehalisCr\Design_CAD_Sheets\Preliminary_Design\SR8MP9.10_B_DE_LWM_003.dgn

NOTES:

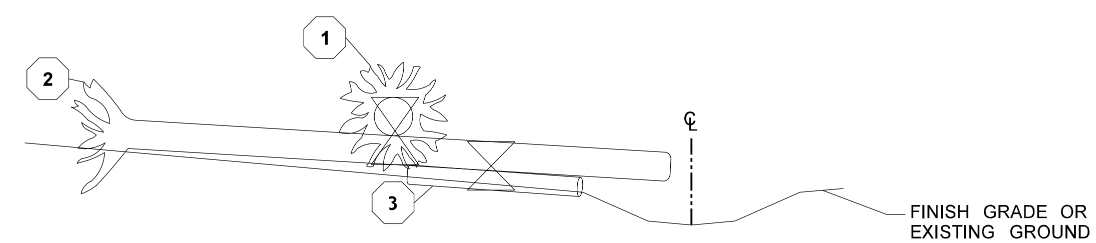
1. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
2. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



PLAN VIEW



SECTION A - SECTION THROUGH LOG 1



SECTION B - SECTION THROUGH LOG 2

LEGEND

- 24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD
- 18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD
- 12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD
- CABLE LASHING, SEE SHEET LWM7-E

LARGE WOOD CLUSTER TYPE D

NTS

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

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DESIGNED BY	K. COMINGS		
ENTERED BY	R. WILCOX		
CHECKED BY	J. GAGE		
PROJ. ENGR.	B. ELLIOTT		
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM6-E

SHEET OF SHEETS

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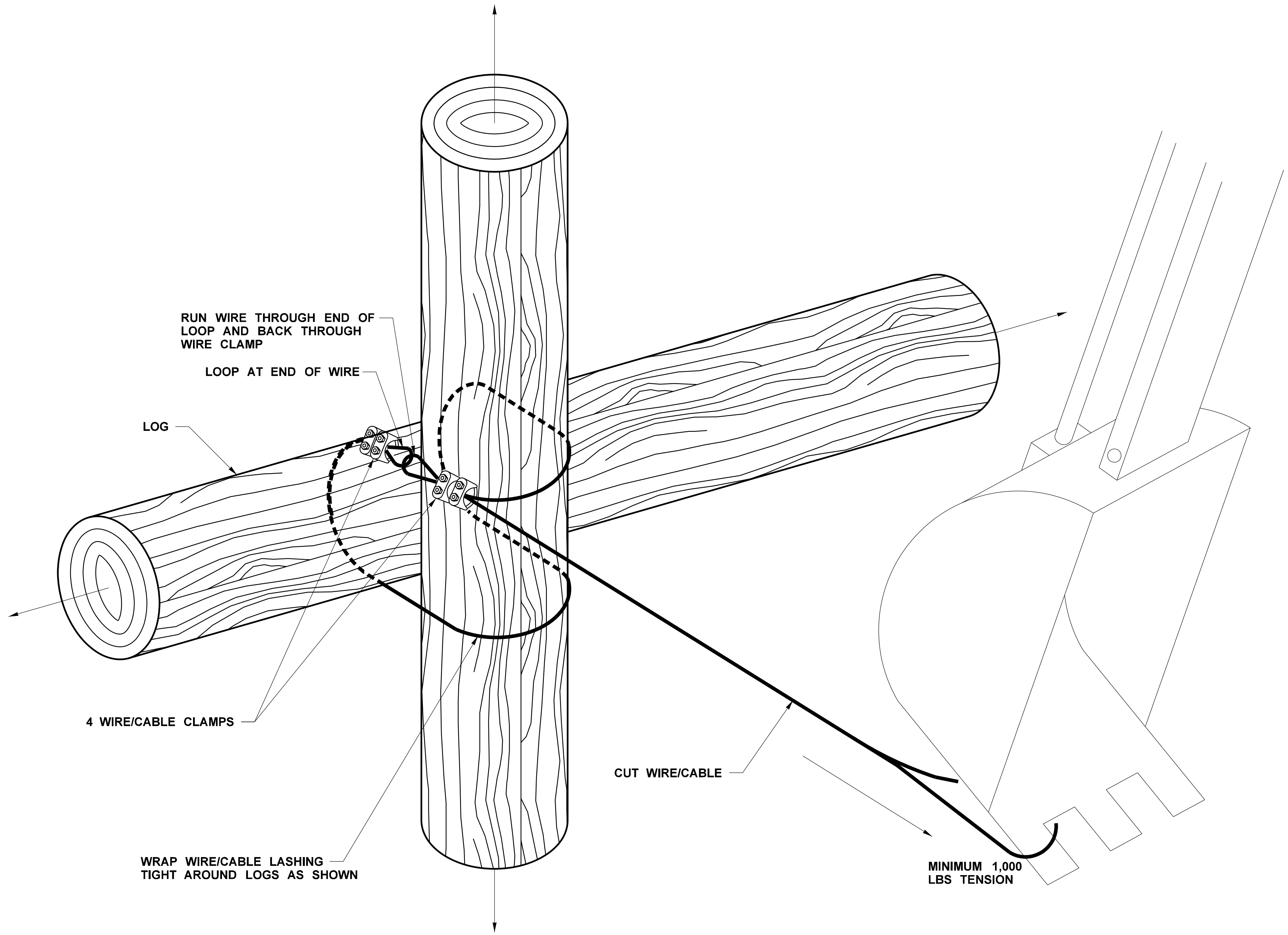

WIRE-ROPE LASHING CONNECTION

NTS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\008\9.10_TribToMoxChehalisCr\Design_CAD_Sheets\Preliminary_Design\SR8MP9.10_B_DE_LWM_004b.dgn

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DESIGNED BY	K. COMINGS			
ENTERED BY	R. WILCOX			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

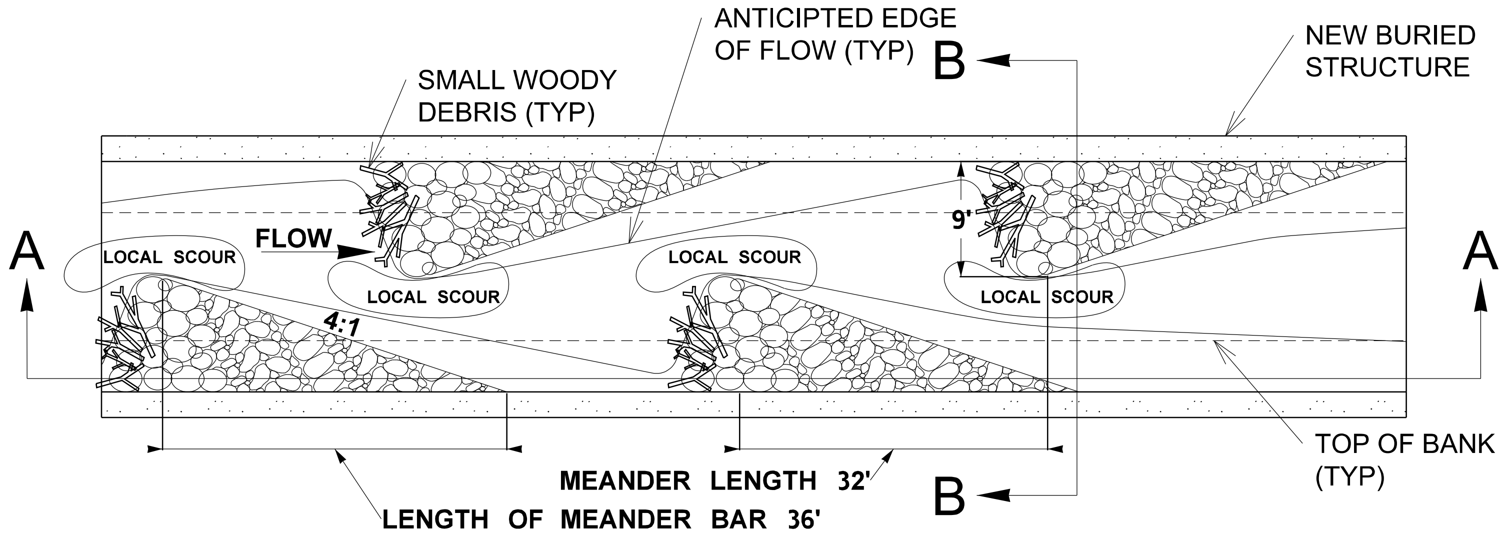
LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM7-E

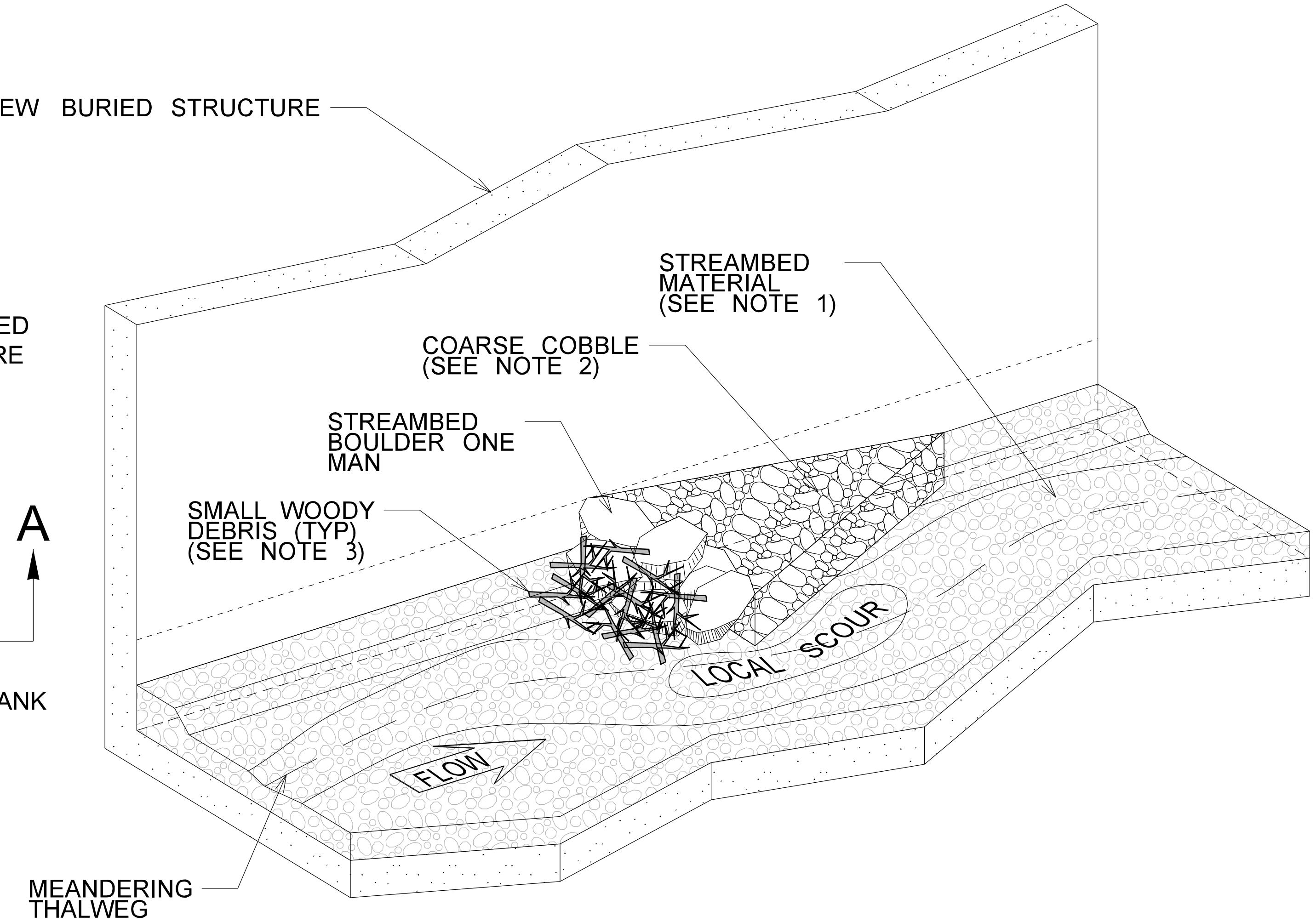
SHEET OF SHEETS

NOTES

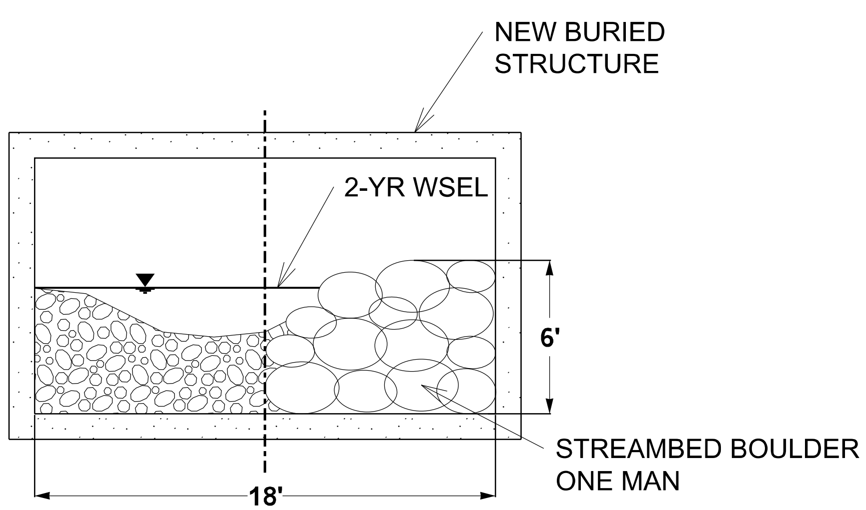
1. STREAMBED MATERIAL SHALL CONSIST OF A WELL GRADED MIX OF 60 PERCENT 4" STREAMBED COBBLES (9-03.11(2)) AND 40 PERCENT STREAMBED SEDIMENT (9-03.11(1)).
2. COARSE COBBLE SHALL CONSIST OF A WELL GRADED MIX OF 70 PERCENT 10" STREAMBED COBBLES (9-03.11(2)) AND 30 PERCENT STREAMBED SEDIMENT (9-03.11(1)).
3. SMALL WOODY DEBRIS SHALL CONSIST OF BRANCHES OR SMALL LOGS THAT HAVE A DIAMETER BETWEEN 2 AND 4 INCHES. SMALL WOOD SHALL HAVE ENDS EMBEDDED AMONG THE ONE-MAN BOULDERS FOR ANCHORING.



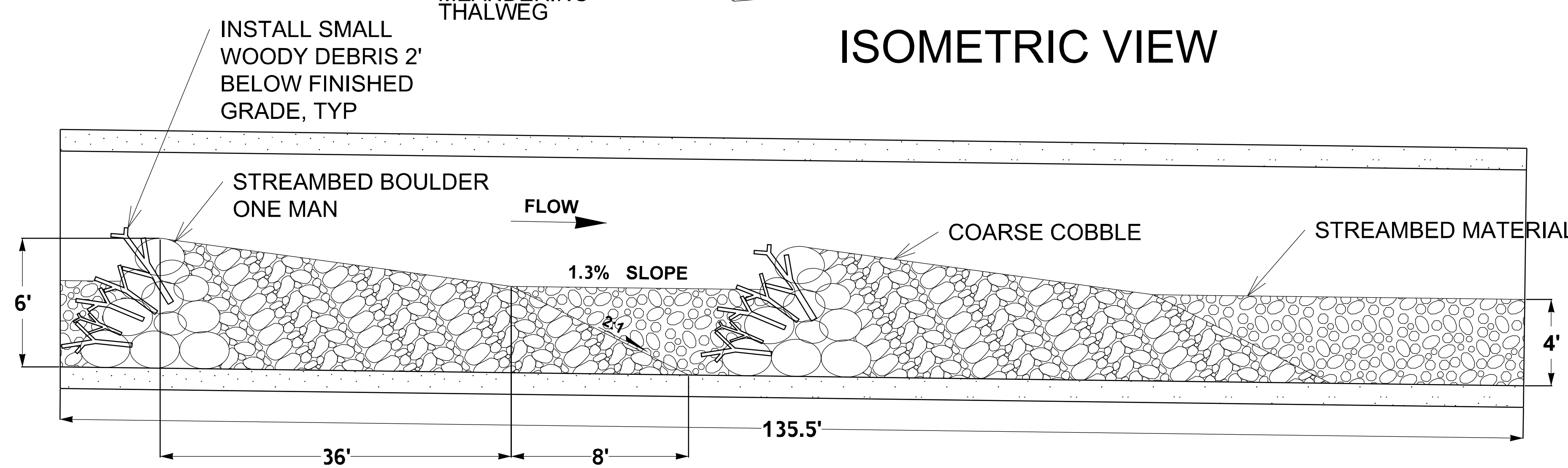
PLAN VIEW



ISOMETRIC VIEW



SECTION B-B



SECTION A-A

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DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

SR 8 MP 9.10 UNNAMED TRIBUTARY TO MOX CHEHALIS CREEK

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

MEANDER BAR DETAILS

PLAN REF NO LWM8-E

SHEET

OF

SHEETS

Appendix E: Manning's Calculations

Not Used

Appendix F: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*US 12*		**Key piece volume**	***1.310***	*yd3*
Stream name	*Mox*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*295.06*	*ft*	**Total wood vol./ft**	***0.3948***	*yd3/ft stream*
Bankfull width	*10*	*ft*	**Total LWM**[c] **pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Log type	*Diameter at midpoint (ft)*	*Length(ft)* [d]	*Volume (yd^3/log)* [d]	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*	DBH based on mid point diameter (ft)
A	2.00	*40*	4.65	**yes**	yes	19	88.43	2.19
B	1.50	*30*	1.96	**yes**	yes	13	25.53	1.63
C	1.00	*20*	0.58	**no**	no	18	10.47	1.16
D			0.00				0.00	
E			0.00				0.00	
F			0.00				0.00	
G			0.00				0.00	
H			0.00				0.00	
I			0.00				0.00	
J			0.00				0.00	
K			0.00				0.00	
L			0.00				0.00	
M			0.00				0.00	
N			0.00				0.00	
O			0.00				0.00	
P			0.00				0.00	

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	32	50	124.4
Targets	**10**	**34**	**116.5**

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Large Wood Structure Stability Analysis

TABLE OF CONTENTS

Date of Last Revision: September 27, 2022

Designer:	Reviewed by:
Roxanne Wilcox	Karen Comings, P.E.

Large Wood Structure Stability Analysis Spreadsheet was developed by Michael Rafferty, P.E.
Version 1.1

Reference for Companion Paper:

Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center.

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

Symbol	Description	Value
FS_V	Factor of Safety for Vertical Force Balance	**1.50**
FS_H	Factor of Safety for Horizontal Force Balance	**1.50**
FS_M	Factor of Safety for Moment Force Balance	**1.50**

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	3.00
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.50
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
Mox	13+04	133	2.46	2.62	31.5	23	47

SR 8 MP 9.10 Unnamed Tributary to Mox
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
Mox	13+04	35.56	Very coarse gravel	5	128.9	80.3	40

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

SR 8 MP 9.10 Unnamed Tributary t
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
Mox	13+04	**Gravel/cobble**	4	137.0	85.3	41

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Coast**	Pseudotsuga menziesii var. menzi.	33.5	38.0
Tree Type #2:				
Tree Type #3:				
Tree Type #4:				
Tree Type #5:				
Tree Type #6:				
Tree Type #7:				
Tree Type #8:				
Tree Type #9:				
Tree Type #10:				

[1] **Air-dried unit weight, γ_{Td}** = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

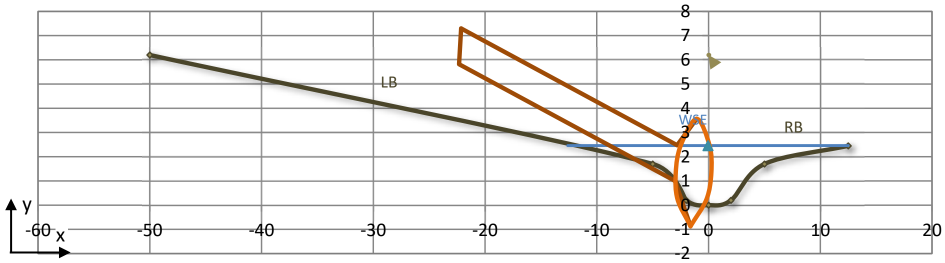
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

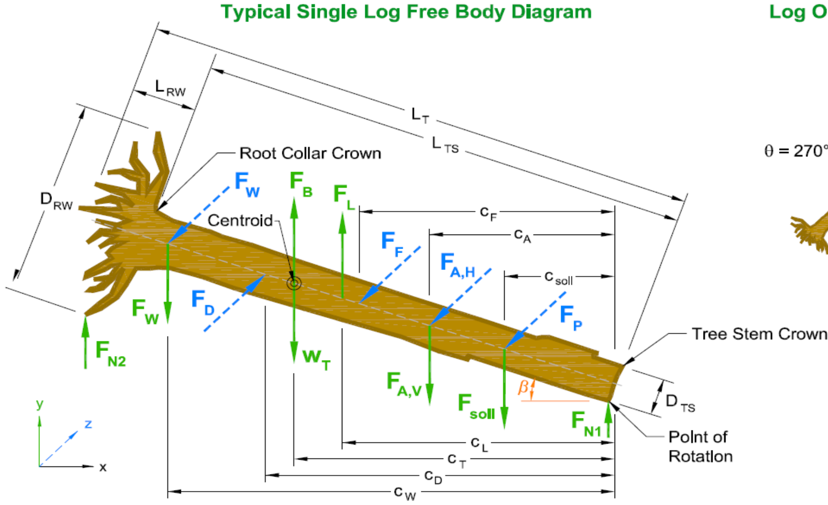


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

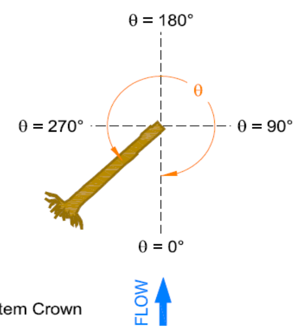
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	135.0	10.0	Root collar: Bottom	-3.00	1.00	-0.87	7.30	14.25

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	41.7	2.0	43.7	1,464	0
↓WS↑Thw	7.3	11.1	18.5	620	1,154
↓Thalweg	0.0	0.7	0.7	26	42
Total	49.0	13.8	62.8	2,110	1,196

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,196	↑
F_L (lbf)	0	
W_T (lbf)	2,110	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	914	↓
FS_V	1.76	

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.63	0.38	0.81	0.43	9.56	907

Horizontal Force Balance

F_D (lbf)	907	→
F_P (lbf)	0	
F_F (lbf)	782	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	125	→
FS_H	0.86	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	349
Bank	4.81	0	2.40	0.87	434
Total	-	0	4.40	-	782

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.3	0.0	24.7	17.3	0.0	24.4	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	19,764
M_r (lbf)	35,879
FS_M	1.82

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

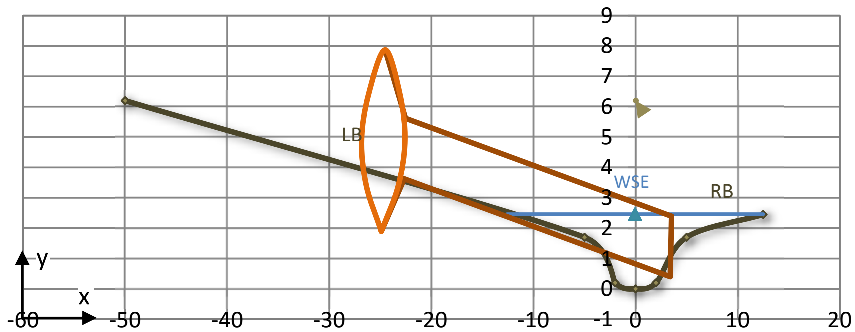
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

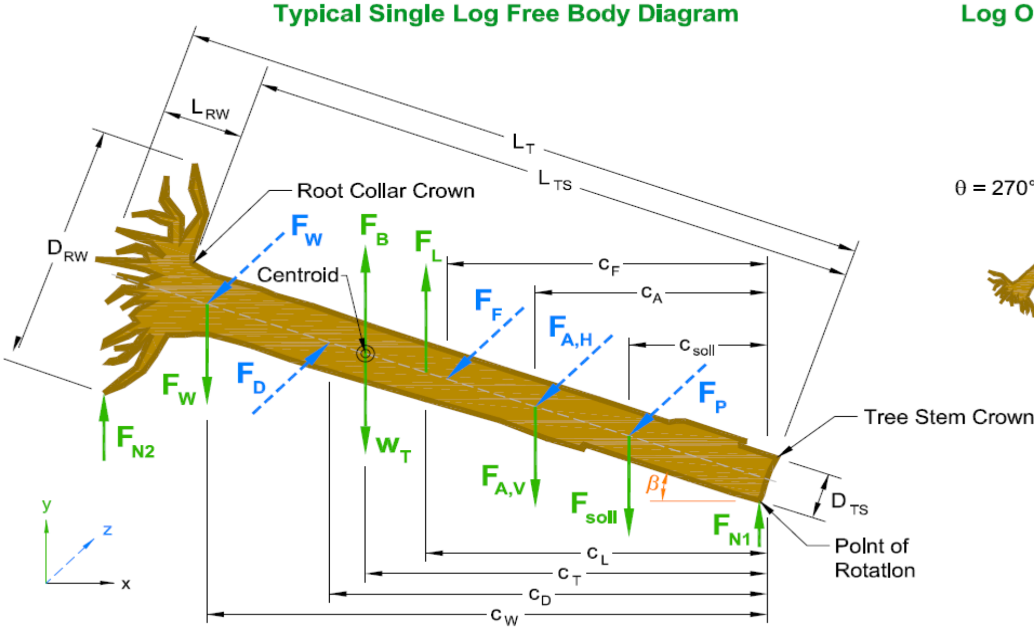


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

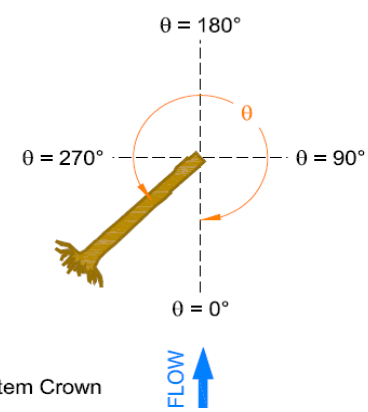
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	225.0	-5.0	Stem tip: Bottom	3.40	0.40	0.40	7.87	16.70

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	77.9	32.2	110.1	3,693	0
↓WS↑Thw	38.3	0.5	38.8	1,303	2,423
↓Thalweg	0.0	0.0	0.0	0	0
Total	116.2	32.7	148.9	4,995	2,423

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,423 ↑
F_L (lbf)	0
W_T (lbf)	4,995 ↓
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	2,572 ↓
FS_V	2.06 ✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.74	0.33	0.76	0.43	18.78	2,087

22.63

Horizontal Force Balance

F_D (lbf)	2,087 →
F_P (lbf)	0
F_F (lbf)	2,228 ←
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	141 ←
FS_H	1.07 ✗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	228
Bank	4.81	0	16.90	0.87	1,999
Total	-	0	18.90	-	2,228

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	11.8	23.0	0.0	17.4	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	99,695
M_r (lbf)	192,744
FS_M	1.93 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

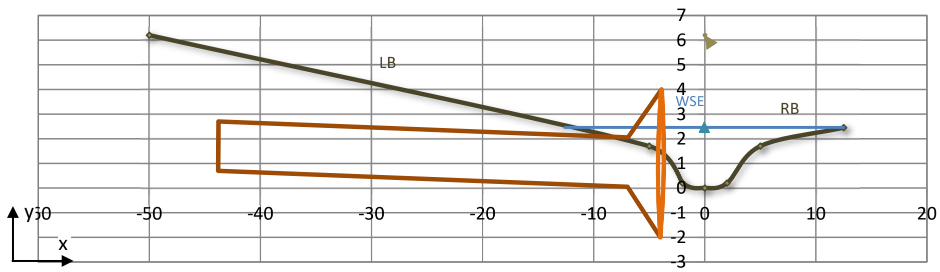
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

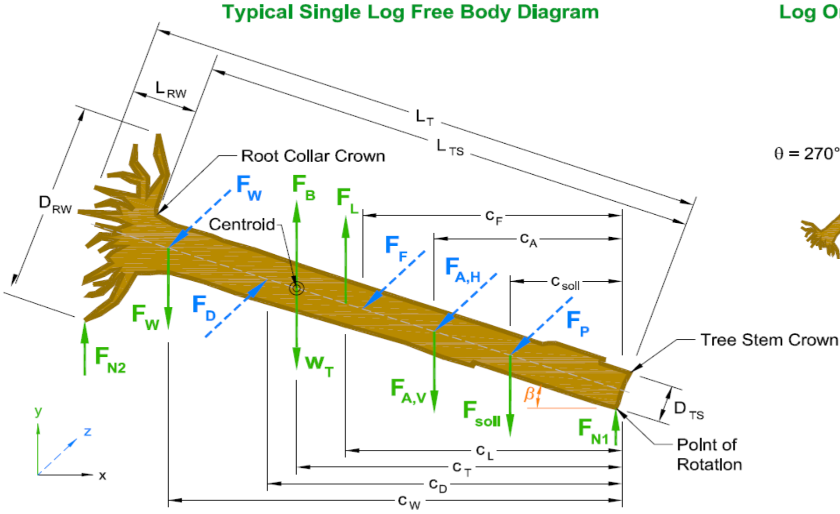


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

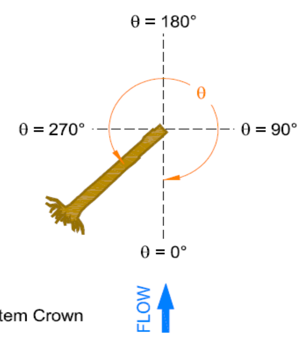
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	85.0	1.0	Rootwad: Bottom	-4.00	-2.00	-2.00	4.00	2.17

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	35.05	2.88	1.44

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	1.2	4.1	5.2	175	0
↓WS↑Thw	115.1	21.6	136.6	4,584	8,526
↓Thalweg	0.0	7.1	7.1	268	440
Total	116.2	32.7	148.9	5,027	8,966

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	8,966
F_L (lbf)	0
W_T (lbf)	5,027
F_{soil} (lbf)	13,487
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	9,548
FS_V	2.06

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	94.3	6.6	100.9	13,487
Total	94.3	6.6	100.9	13,487

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.10	0.33	1.02	0.43	1.79	26

Horizontal Force Balance

F_D (lbf)	26
F_P (lbf)	32,470
F_F (lbf)	8,286
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	40,731
FS_H	1,576.84

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	381
Bank	4.81	32,470	40.00	0.87	7,904
Total	-	32,470	42.00	-	8,286

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.1	0.0	37.6	23.1	17.5	20.0	23.3

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	207,970
M_r (lbf)	1,466,188
FS_M	7.05

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

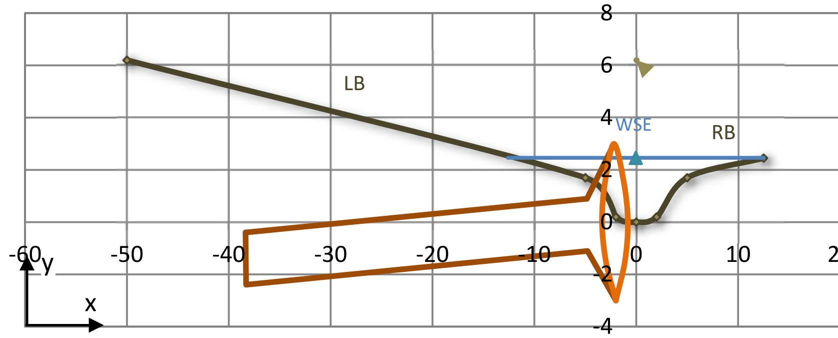
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Key Log	A Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

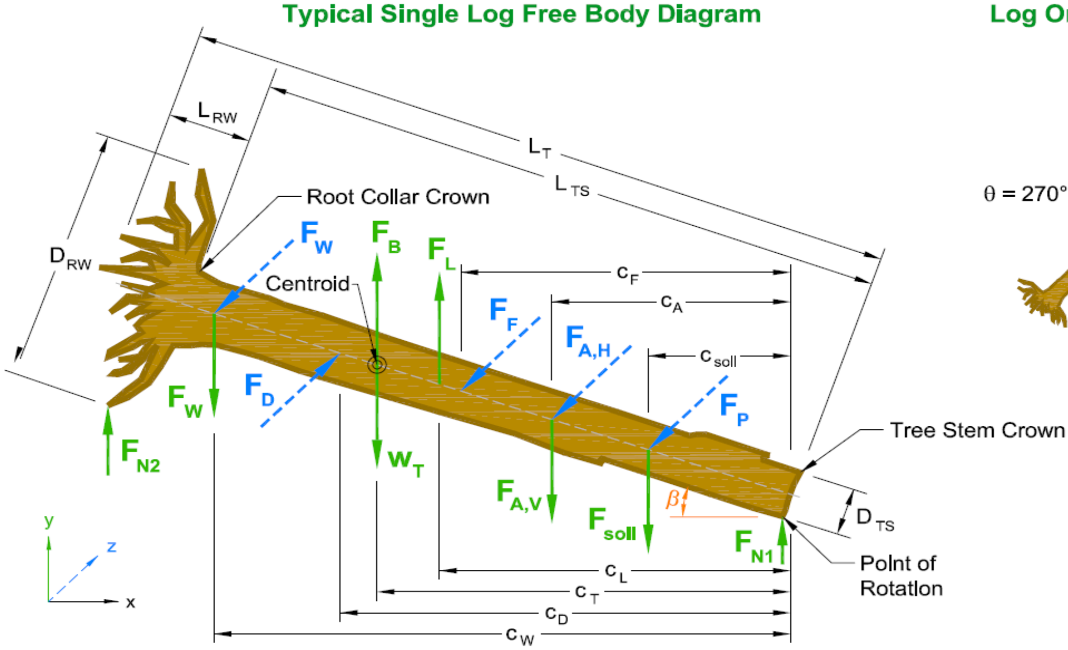


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

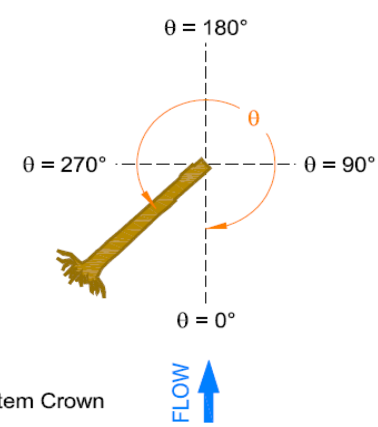
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	65.0	-2.0	Rootwad: Bottom	-2.00	-3.00	-3.00	3.00	5.70

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	38.49	5.43	3.01

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.3	0.3	10	0
↓WS↑Thw	14.6	15.6	30.3	1,016	1,889
↓Thalweg	101.6	16.7	118.3	4,497	7,384
Total	116.2	32.7	148.9	5,522	9,273

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,273
F_L (lbf)	0
W_T (lbf)	5,522
F_{soil} (lbf)	23,528
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	19,777
FS_V	3.13

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	73.2	158.2	231.4	23,528
Total	73.2	158.2	231.4	23,528

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.25	0.33	1.21	0.43	2.97	113

Horizontal Force Balance

F_D (lbf)	113
F_P (lbf)	56,643
F_F (lbf)	17,163
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	73,694
FS_H	655.03

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	790
Bank	4.81	56,643	40.00	0.87	16,373
Total	-	56,643	42.00	-	17,163

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.8	0.0	39.3	22.8	19.2	20.0	25.6

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	216,077
M_r (lbf)	2,765,038
FS_M	12.80

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

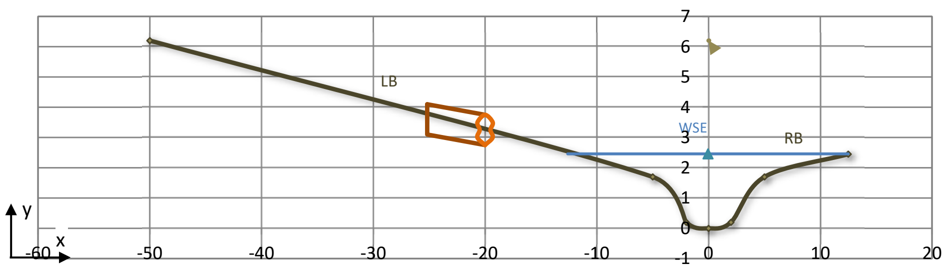
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

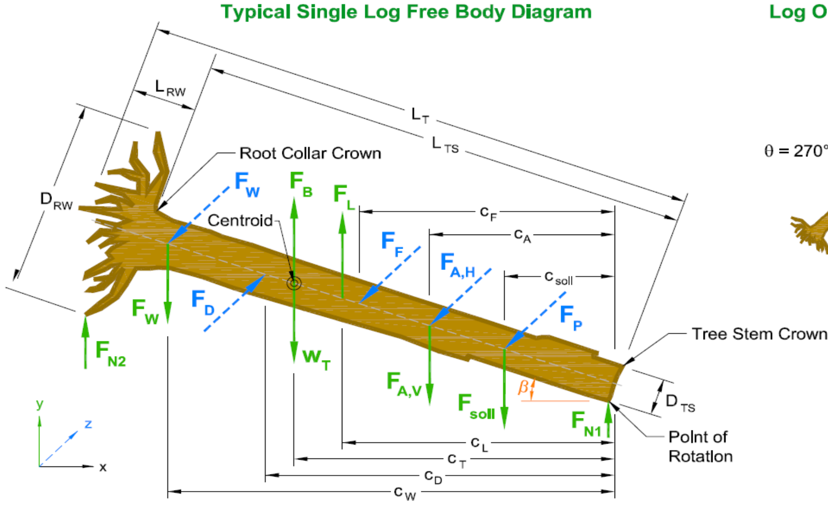


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

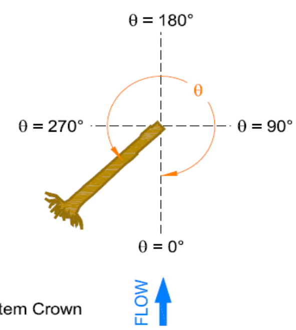
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	165.0	1.0	Root collar: Bottom	-20.00	2.75	2.75	4.10	0.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	15.7	0.0	15.7	527	0
↓WS↑Thw	0.0	0.0	0.0	0	0
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	0

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	0	
F_L (lbf)	0	
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	527	↓
FS_V	#DIV/0!	#DIV/0!

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.46	0.62	0.00	0.61	0

Horizontal Force Balance

F_D (lbf)	0	
F_P (lbf)	0	
F_F (lbf)	457	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	457	←
FS_H	913.42	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	40
Bank	4.81	0	20.00	0.87	416
Total	-	0	22.00	-	457

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	0.0	10.0	0.0	10.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	10	
M_r (lbf)	15,103	
FS_M	1,510.81	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

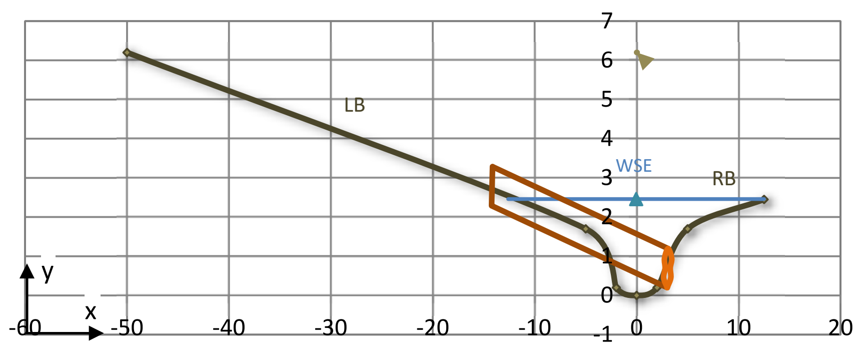
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

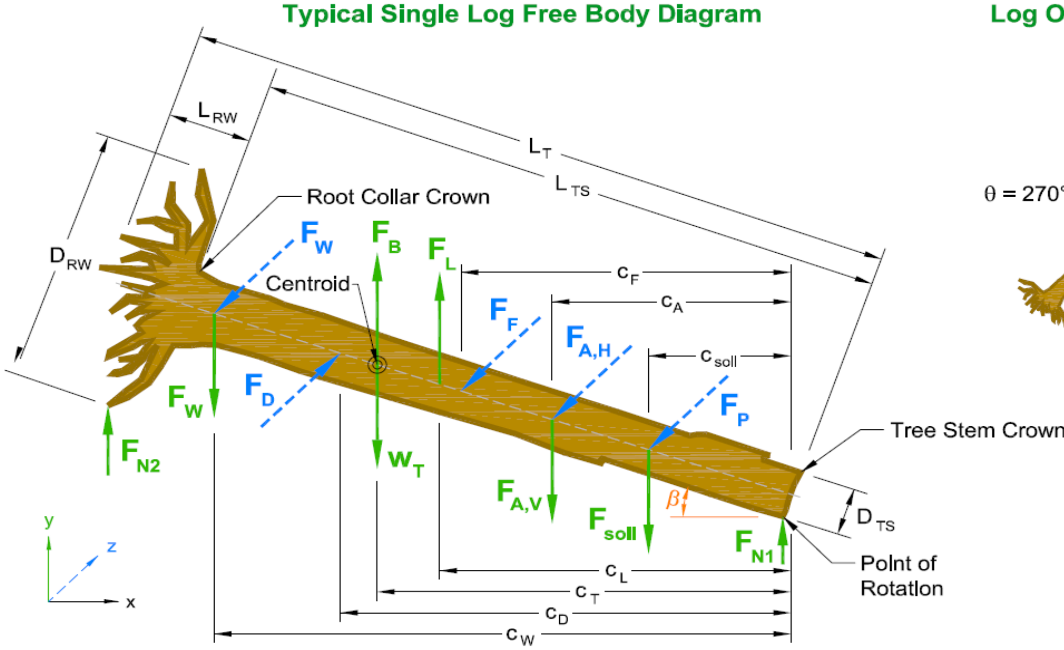


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

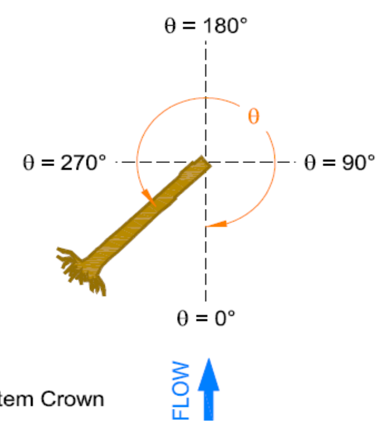
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	120.0	6.0	Root collar: Bottom	3.00	0.20	0.20	3.29	10.12

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	2.5	0.0	2.5	85	0
↓WS↑Thw	13.2	0.0	13.2	442	822
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	822

Lift Force

C_{LT}	0.04
F_L (lbf)	3

Vertical Force Balance

F_B (lbf)	822
F_L (lbf)	3
W_T (lbf)	527
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	297
FS_V	0.64

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.45	0.46	1.02	0.43	4.90	330

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	13.20	0.87	0
Total	-	0	15.20	-	0

Horizontal Force Balance

F_D (lbf)	330
F_P (lbf)	0
F_F (lbf)	0
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	330
FS_H	0.00

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	15.8	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	11,463
M_r (lbf)	5,241
FS_M	0.46

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

Cluster A Total Forces

Vertical Force Balance

ΣF_V (lbf)	11,435	↓

Horizontal Force Balance

ΣF_H (lbf)	40,873	←

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

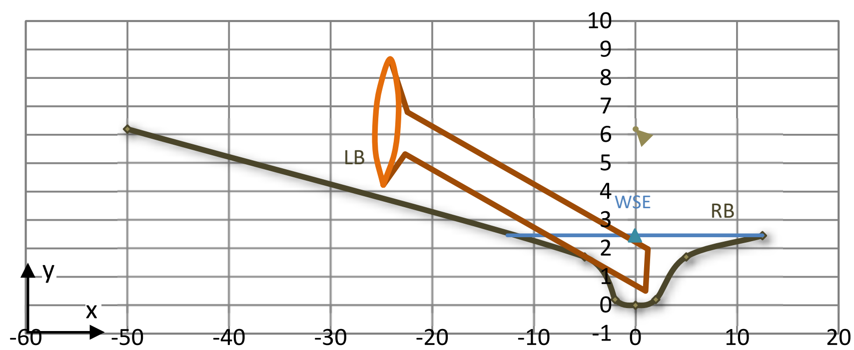
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

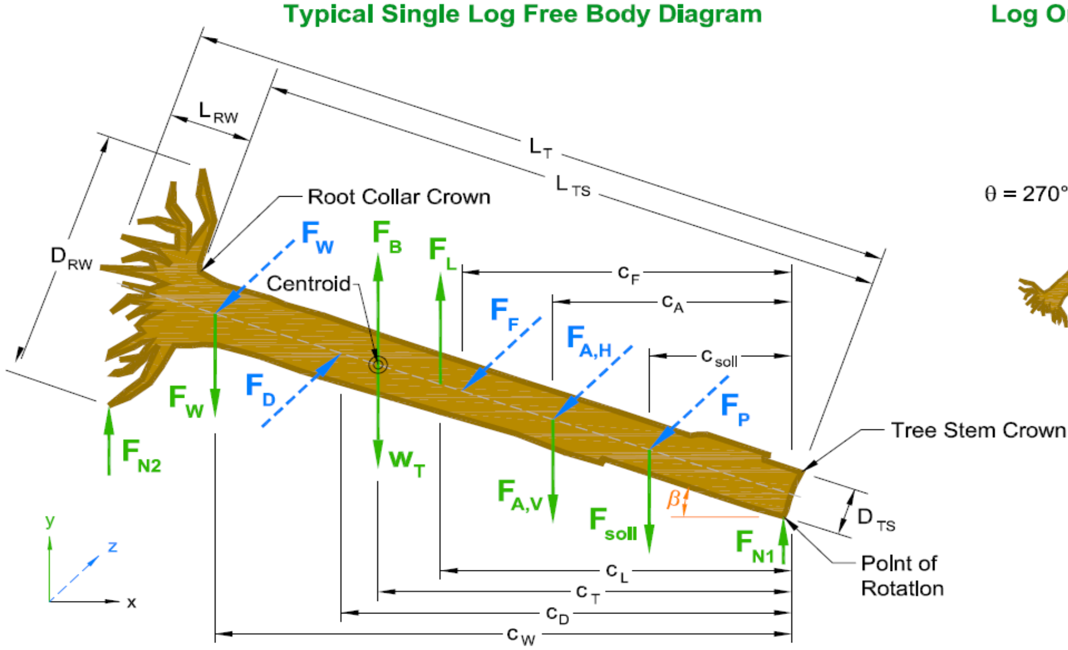


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

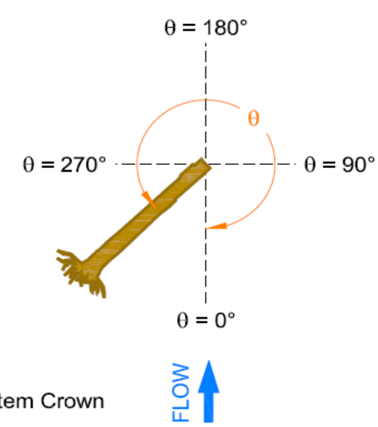
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	300.0	-10.0	Stem tip: Bottom	1.00	0.50	0.50	8.66	9.14

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	36.6	13.8	50.4	1,690	0
↓WS↑Thw	12.4	0.0	12.4	417	776
↓Thalweg	0.0	0.0	0.0	0	0
Total	49.0	13.8	62.8	2,107	776

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	776
F_L (lbf)	0
W_T (lbf)	2,107
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,332
FS_V	2.72

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.40	0.38	1.02	0.43	4.19	255

Horizontal Force Balance

F_D (lbf)	255
F_P (lbf)	0
F_F (lbf)	1,117
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	863
FS_H	4.39

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	1,117
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	1,117

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	0.0	5.6	17.2	0.0	30.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	15,863
M_r (lbf)	26,478
FS_M	1.67

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

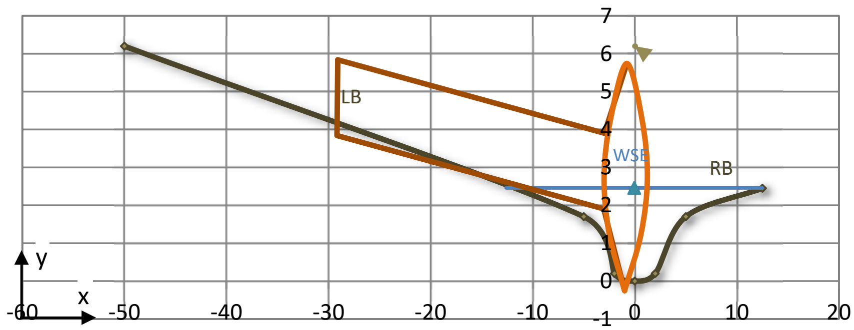
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

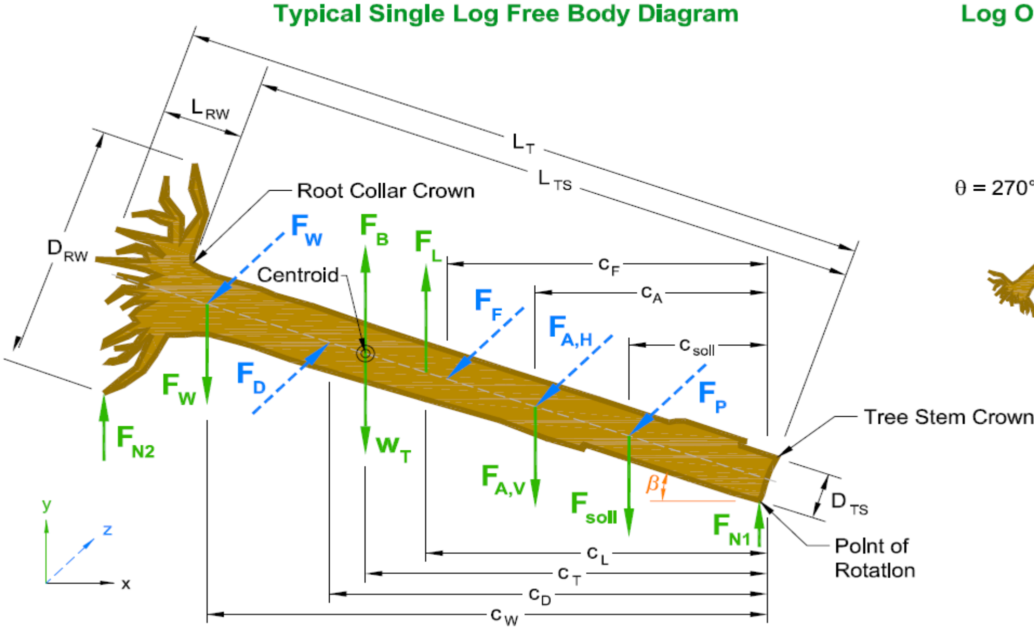


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

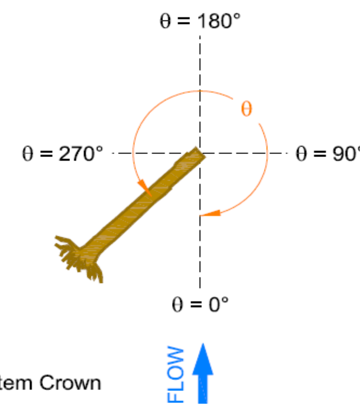
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	3.0	Rootwad: Bottom	-1.00	-0.25	-0.25	5.84	65.09

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	113.1	19.6	132.7	4,453	0
↓WS↑Thw	3.1	13.0	16.1	541	1,006
↓Thalweg	0.0	0.0	0.0	2	3
Total	116.2	32.7	148.9	4,996	1,009

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,009
F_L (lbf)	0
W_T (lbf)	4,996
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	3,987
FS_V	4.95

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
2.88	0.33	1.12	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!
F_P (lbf)	0
F_F (lbf)	3,451
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	#NUM!
FS_H	#NUM!

#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	401
Bank	4.81	0	14.70	0.87	3,051
Total	-	0	16.70	-	3,451

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	#NUM!	23.0	0.0	7.3	0.0

*Distances are from the stem tip

Point of Rotation:	Rootwad

Moment Force Balance

M_d (lbf)	#NUM!
M_r (lbf)	327,742
FS_M	#NUM!

#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

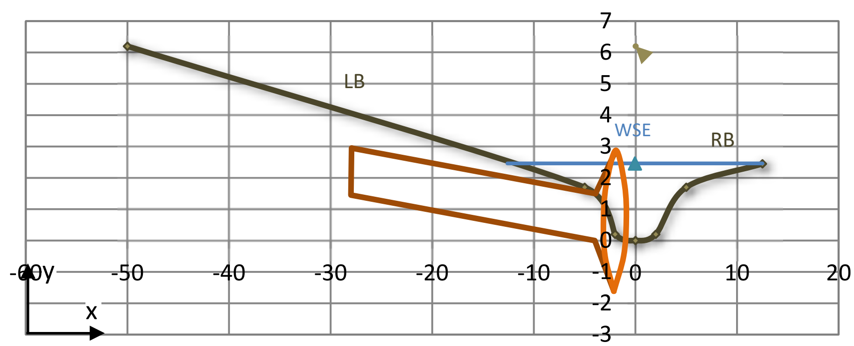
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

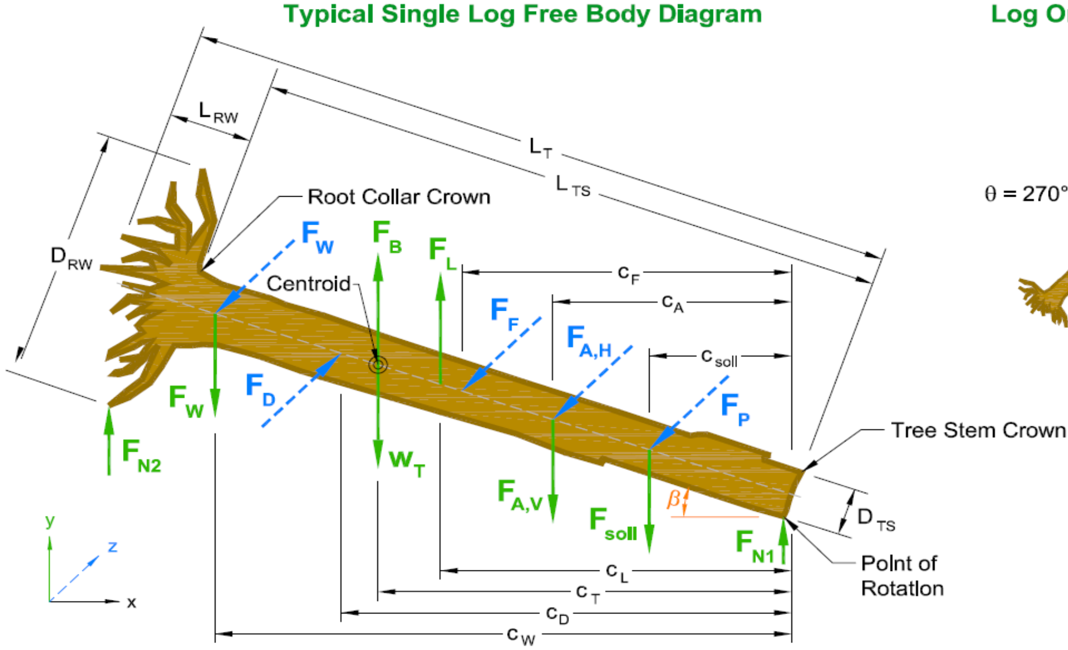


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

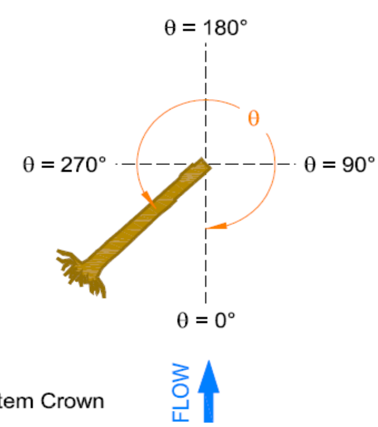
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	120.0	3.0	Root collar: Bottom	-4.00	0.00	-1.62	2.95	6.55

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	26.88	1.04	0.58

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	2.0	0.2	2.1	71	0
↓WS↑Thw	47.1	10.3	57.3	1,923	3,578
↓Thalweg	0.0	3.4	3.4	128	210
Total	49.0	13.8	62.8	2,122	3,788

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	3,788	↑
F_L (lbf)	0	
W_T (lbf)	2,122	↓
F_{soil} (lbf)	2,881	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,216	↓
FS_V	1.32	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	16.9	6.6	23.5	2,881
Total	16.9	6.6	23.5	2,881

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.29	0.38	0.94	0.43	2.76	120

Horizontal Force Balance

F_D (lbf)	120	→
F_P (lbf)	6,936	←
F_F (lbf)	1,054	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	7,870	←
FS_H	66.46	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.08	0.84	66
Bank	4.81	6,936	29.92	0.87	988
Total	-	6,936	32.00	-	1,054

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.3	0.0	28.5	17.3	13.4	15.0	17.9

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	68,963	
M_r (lbf)	233,339	
FS_M	3.38	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

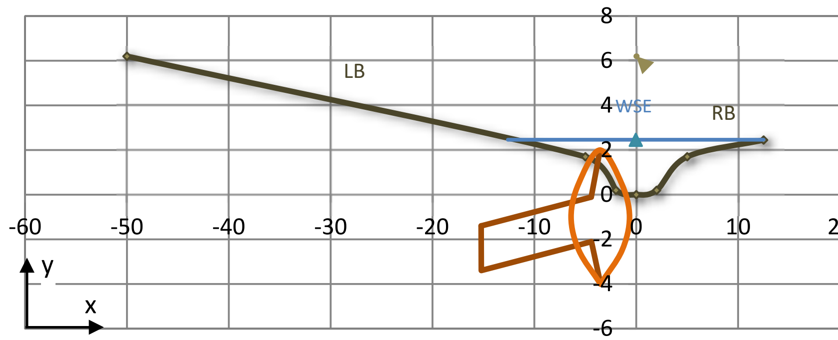
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Key Log	B Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

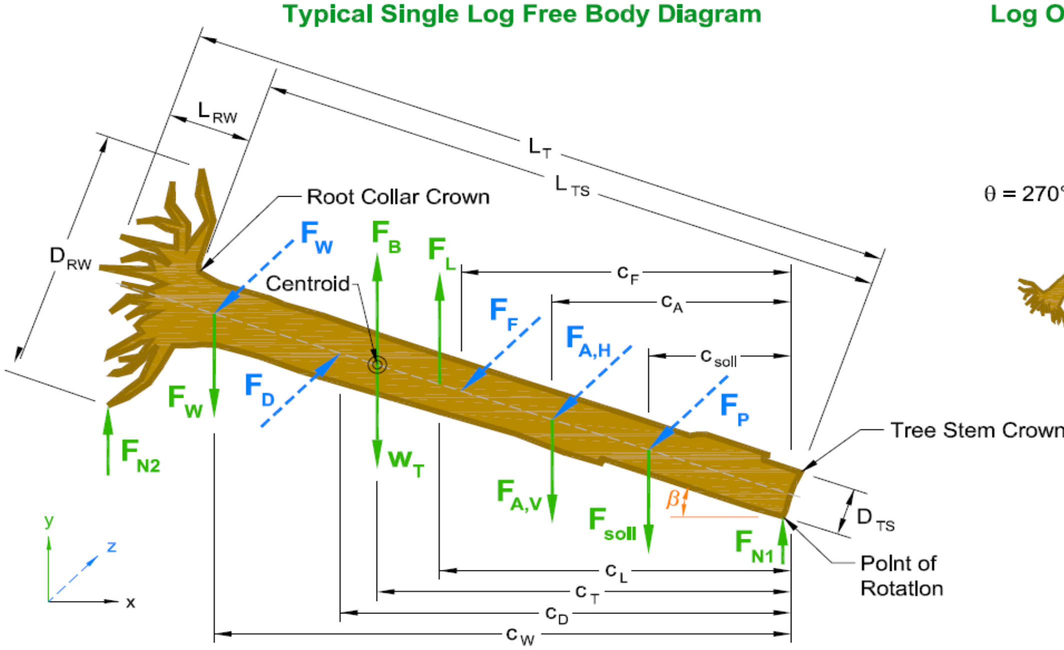


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

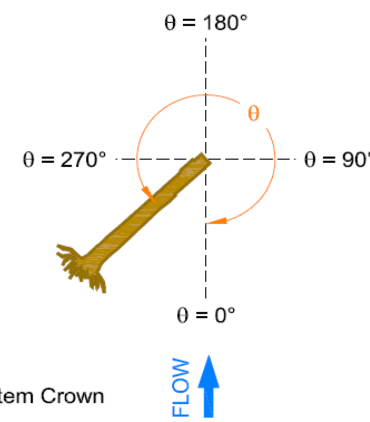
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	17.0	-2.0	Rootwad: Bottom	-3.50	-4.00	-4.00	2.00	7.89

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	40.00	4.12	2.80

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	6.9	6.9	232	432
↓Thalweg	116.2	25.8	142.0	5,396	8,860
Total	116.2	32.7	148.9	5,628	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292
F_L (lbf)	0
W_T (lbf)	5,628
F_{soil} (lbf)	19,247
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	15,582
FS_V	2.68

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	2.4	221.8	224.2	19,247
Total	2.4	221.8	224.2	19,247

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.35	0.33	1.24	0.00	2.98	157

Horizontal Force Balance

F_D (lbf)	157
F_P (lbf)	46,336
F_F (lbf)	13,523
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	59,702
FS_H	381.90

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	623
Bank	4.81	46,336	40.00	0.87	12,901
Total	-	46,336	42.00	-	13,523

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.9	0.0	0.0	22.9	20.0	20.0	20.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	165,045
M_r (lbf)	1,988,773
FS_M	12.05

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

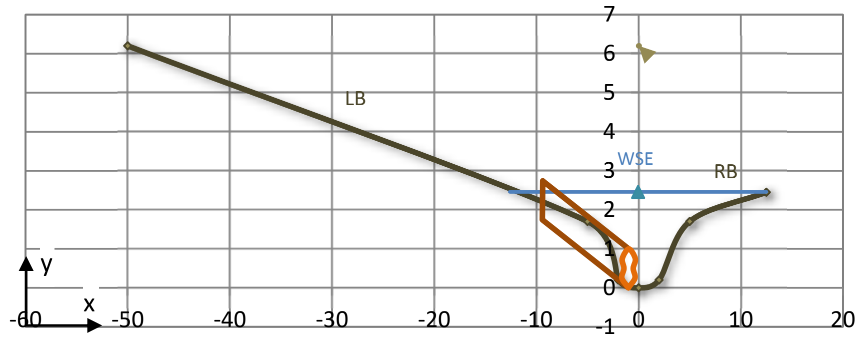
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

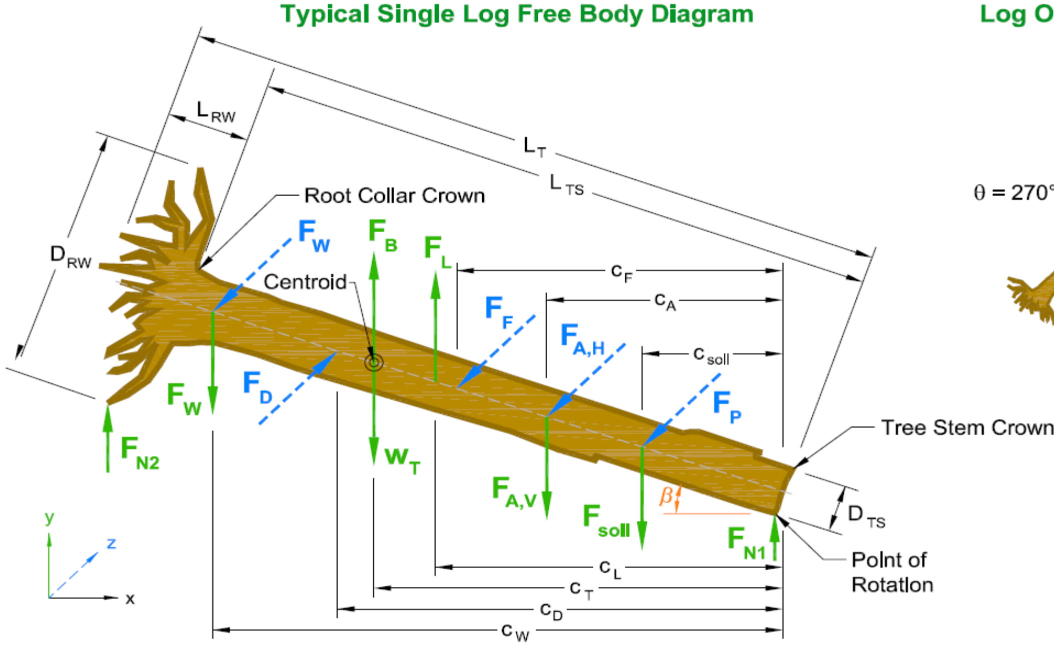


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

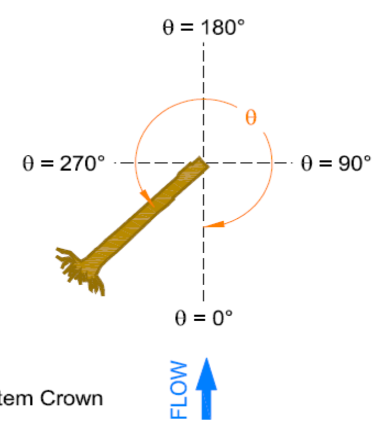
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	25.0	5.0	Root collar: Bottom	-1.00	0.00	0.00	2.74	4.16

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.2	0.0	0.2	8	0
↓WS↑Thw	15.5	0.0	15.5	519	965
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	965

Lift Force

C_{LT}	0.01
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	965	↑
F_L (lbf)	0	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	438	↑
FS_V	0.55	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.18	0.46	0.54	0.43	1.48	41

Horizontal Force Balance

F_D (lbf)	41	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	41	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	4.15	0.84	0
Bank	4.81	0	17.45	0.87	0
Total	-	0	21.60	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	17.7	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	10,021
M_r (lbf)	5,249
FS_M	0.52

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

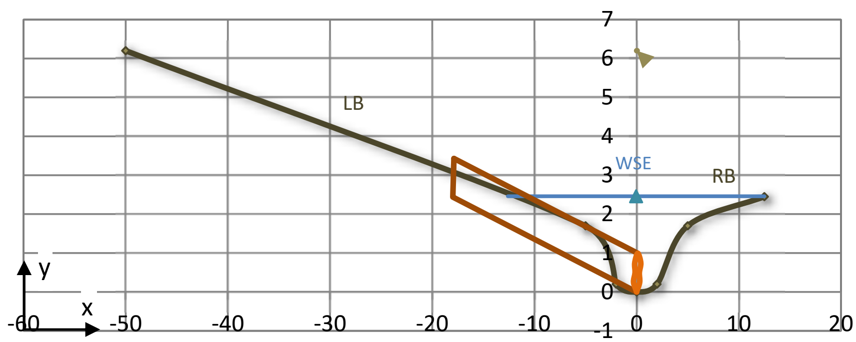
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

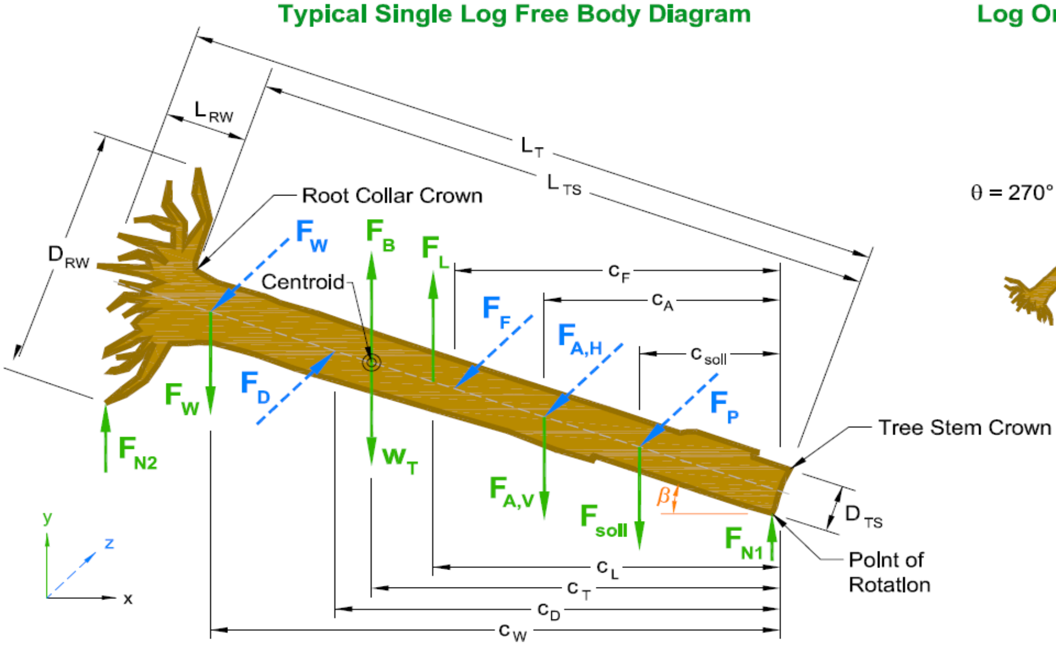


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

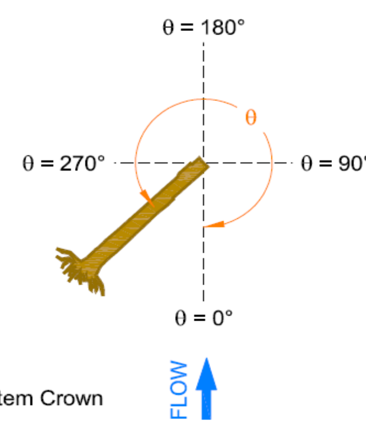
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	115.0	7.0	Root collar: Bottom	0.00	0.00	0.00	3.43	4.50

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.52	0.01	0.01

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	3.1	0.0	3.1	103	0
↓WS↑Thw	12.6	0.0	12.6	424	788
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	788

Lift Force

C_{LT}	0.05
F_L (lbf)	2

Vertical Force Balance

F_B (lbf)	788	↑
F_L (lbf)	2	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	262	↑
FS_V	0.67	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.20	0.46	1.08	0.43	2.38	71

Horizontal Force Balance

F_D (lbf)	71	→
F_P (lbf)	1	←
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	70	→
FS_H	0.01	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.05	0.84	0
Bank	4.81	1	17.35	0.87	0
Total	-	1	19.40	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	18.7	9.9	10.0	14.1	0.0	14.1

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	8,539
M_r (lbf)	5,237
FS_M	0.61

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

Cluster B Total Forces

Vertical Force Balance

ΣF_V (lbf)	5,833	↓

Horizontal Force Balance

ΣF_H (lbf)	8,622	←

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

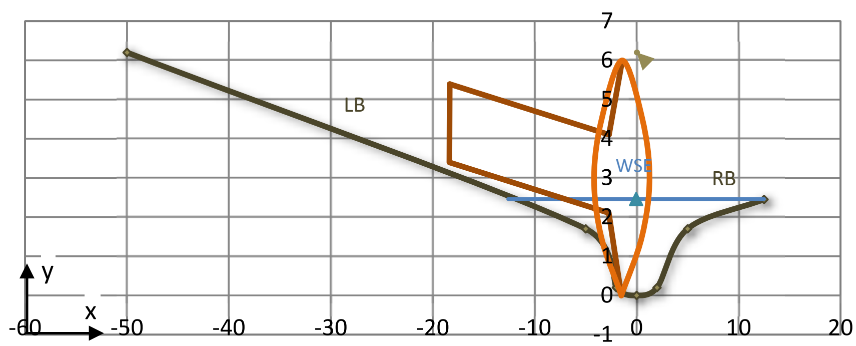
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Key Log	C Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

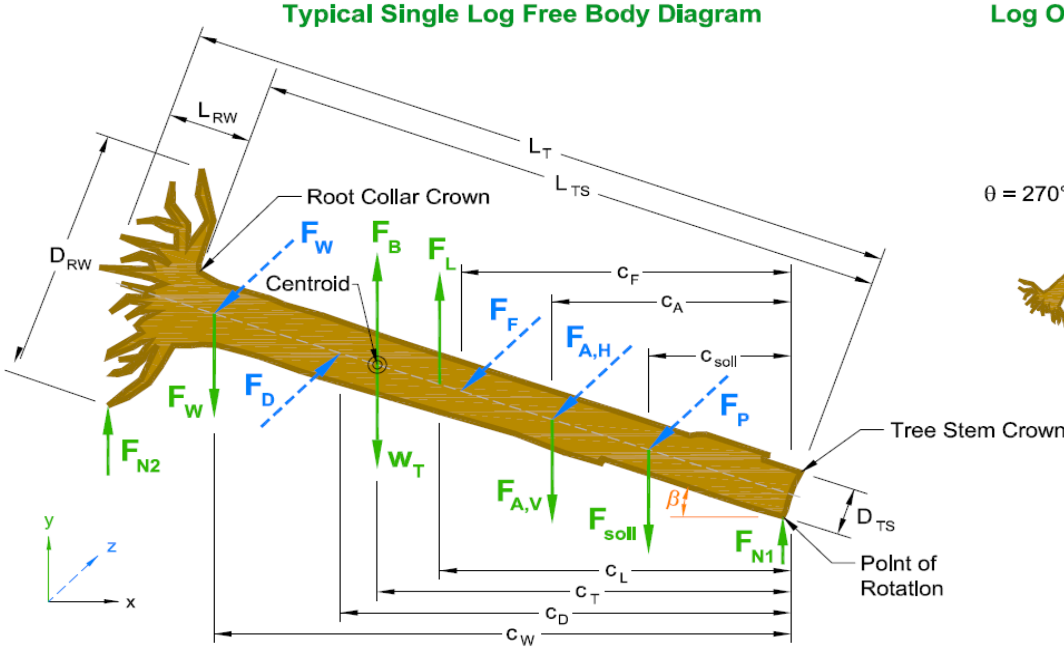


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

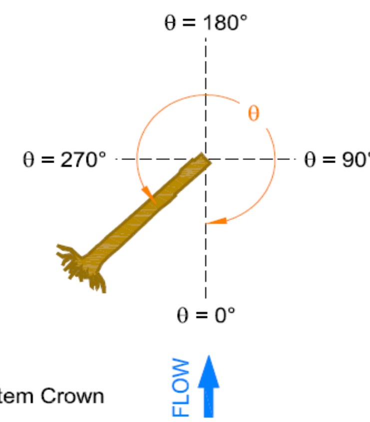
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	155.0	2.0	Rootwad: Bottom	-1.50	0.00	0.00	6.00	43.72

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	114.7	21.8	136.5	4,578	0
↓WS↑Thw	1.6	10.9	12.5	418	777
↓Thalweg	0.0	0.0	0.0	0	0
Total	116.2	32.7	148.9	4,995	777

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	777	↑
F_L (lbf)	0	
W_T (lbf)	4,995	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	4,218	↓
FS_V	6.43	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
1.93	0.33	0.76	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!
F_P (lbf)	0
F_F (lbf)	3,539
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	#NUM!
FS_H	#NUM!

#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	3,539
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	3,539

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	#NUM!	23.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	#NUM!
M_r (lbf)	395,042
FS_M	#NUM!

#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

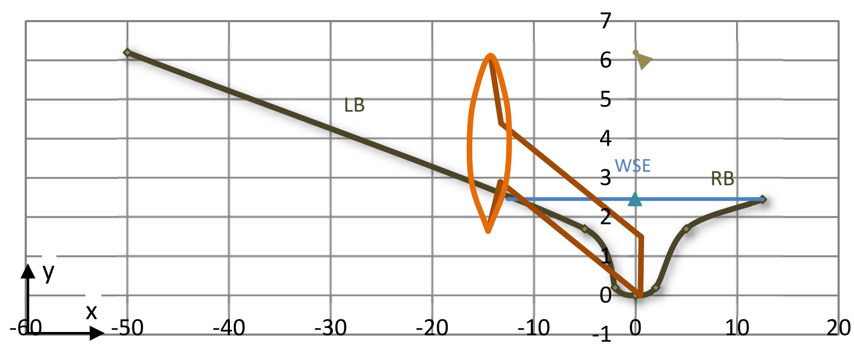
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

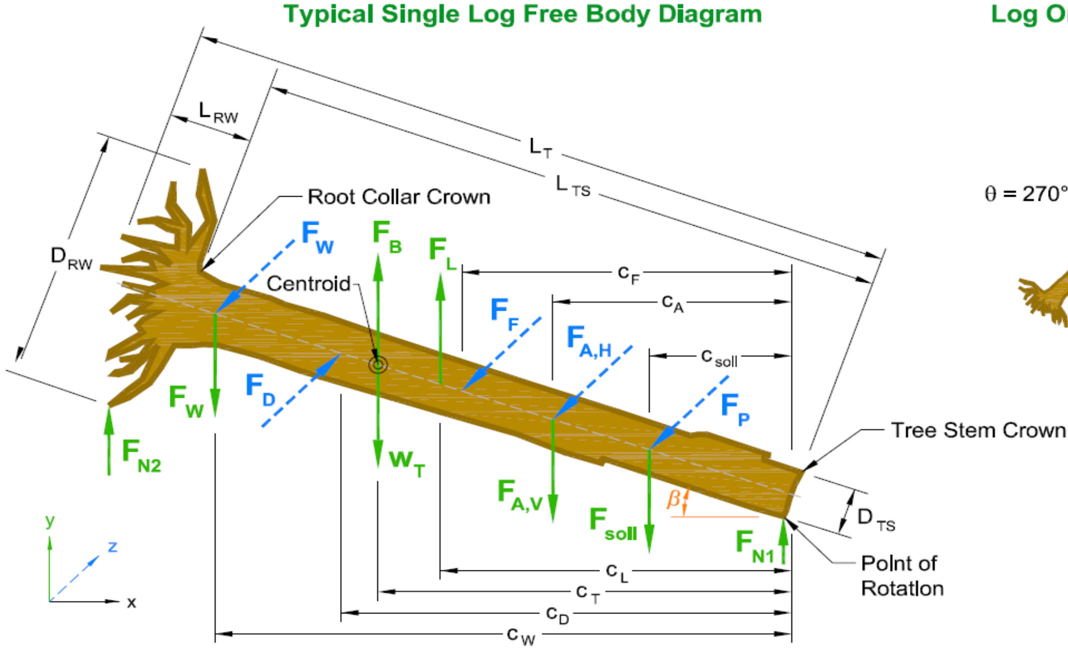


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

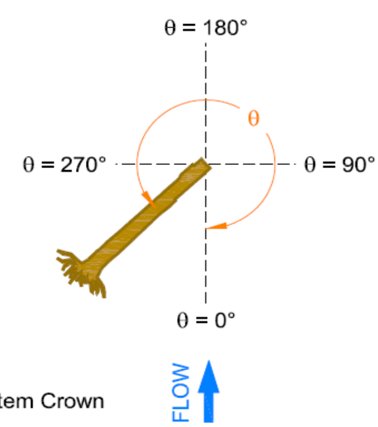
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	210.0	-6.0	Stem tip: Bottom	0.50	0.00	0.00	6.12	12.32

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	20.1	12.8	32.9	1,103	0
↓WS↑Thw	29.0	1.0	29.9	1,005	1,869
↓Thalweg	0.0	0.0	0.0	0	0
Total	49.0	13.8	62.8	2,107	1,869

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,869
F_L (lbf)	0
W_T (lbf)	2,107
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	239
FS_V	1.13

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.54	0.38	0.56	0.43	5.00	410

Horizontal Force Balance

F_D (lbf)	410
F_P (lbf)	0
F_F (lbf)	206
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	204
FS_H	0.50

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.38	0.84	31
Bank	4.81	0	13.20	0.87	176
Total	-	0	15.58	-	206

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	0.0	11.7	17.2	0.0	13.7	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	31,179
M_r (lbf)	33,949
FS_M	1.09

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

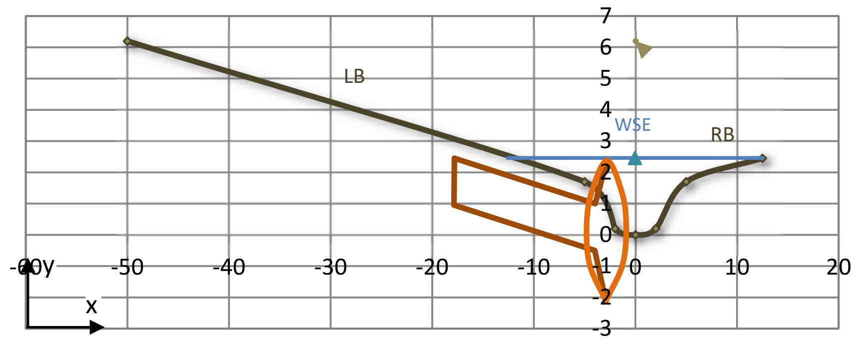
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

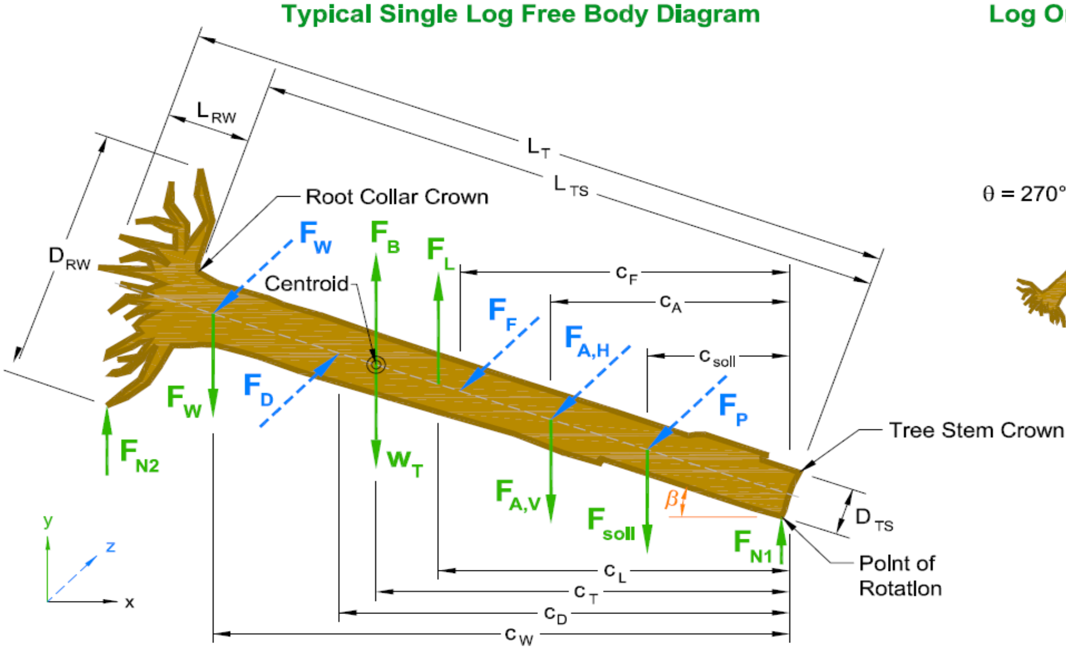


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

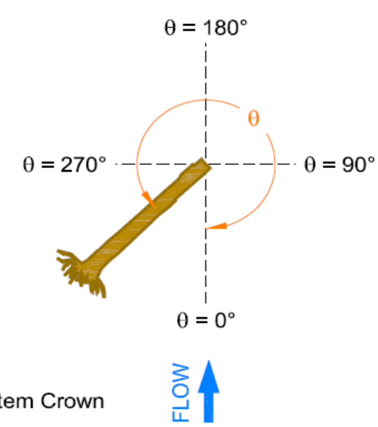
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	150.0	3.0	Root collar: Bottom	-4.00	-0.50	-2.12	2.45	7.42

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	28.67	0.59	0.53

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	47.0	7.9	54.9	1,841	3,424
↓Thalweg	2.0	5.9	7.9	302	496
Total	49.0	13.8	62.8	2,143	3,920

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	3,920	↑
F_L (lbf)	0	
W_T (lbf)	2,143	↓
F_{soil} (lbf)	2,172	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	395	↓
FS_V	1.10	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	4.1	18.9	23.0	2,172
Total	4.1	18.9	23.0	2,172

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.33	0.38	0.77	0.43	2.71	134

Horizontal Force Balance

F_D (lbf)	134	→
F_P (lbf)	5,229	←
F_F (lbf)	342	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	5,438	←
FS_H	41.53	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	21
Bank	4.81	5,229	30.00	0.87	322
Total	-	5,229	32.00	-	342

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.4	0.0	29.4	17.4	14.3	15.0	19.1

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	71,955	
M_r (lbf)	179,039	
FS_M	2.49	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

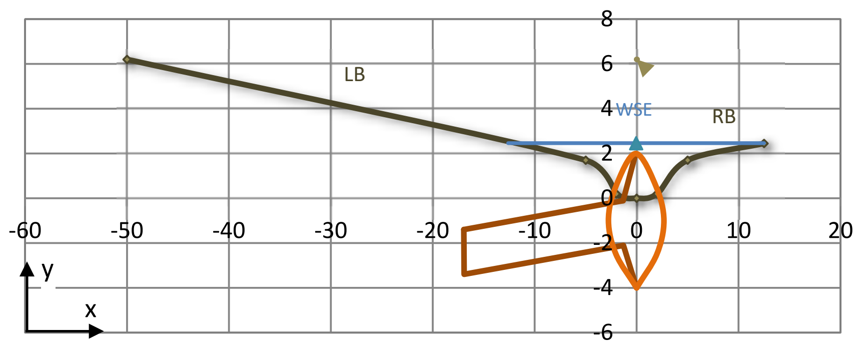
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Key Log	C Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

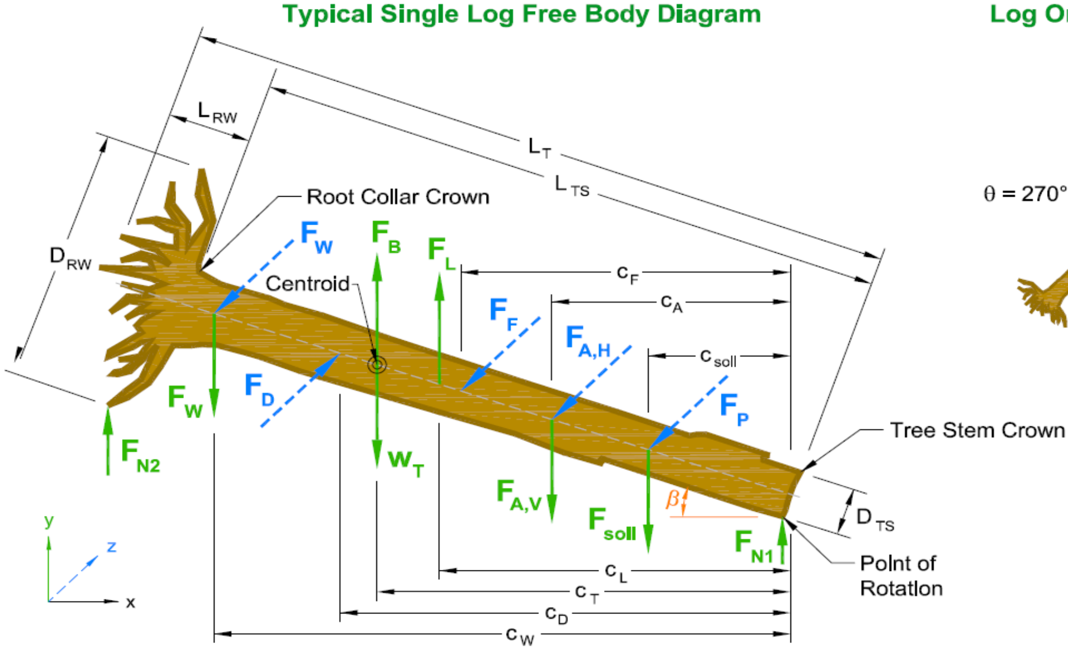


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

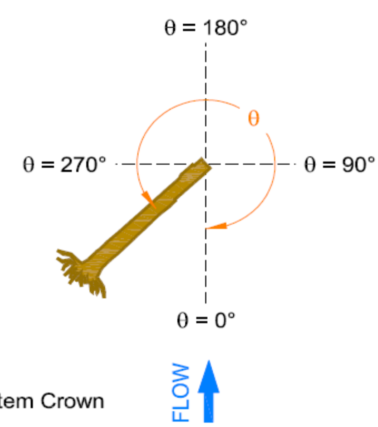
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	25.0	-2.0	Rootwad: Bottom	0.00	-4.00	-4.00	2.00	7.48

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	4.60	0.35	0.18
Bank	Gravel/cobble	137.0	85.3	41.0	4	35.40	4.29	2.81

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	6.9	6.9	232	432
↓Thalweg	116.2	25.8	142.0	5,396	8,860
Total	116.2	32.7	148.9	5,628	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	0	
W_T (lbf)	5,628	↓
F_{soil} (lbf)	17,329	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	13,665	↓
FS_V	2.47	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	1.6	1.6	131
Bank	4.5	194.4	198.9	17,198
Total	4.5	196.0	200.5	17,329

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.33	0.33	1.24	0.00	2.81	140

Horizontal Force Balance

F_D (lbf)	140	→
F_P (lbf)	41,706	←
F_F (lbf)	11,815	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	53,381	←
FS_H	382.06	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	302	6.50	0.84	1,775
Bank	4.81	41,404	35.50	0.87	10,040
Total	-	41,706	42.00	-	11,815

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.9	0.0	0.0	22.9	20.0	20.0	20.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	164,379
M_r (lbf)	1,785,438
FS_M	10.86 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by
Michael Rafferty, P.E.

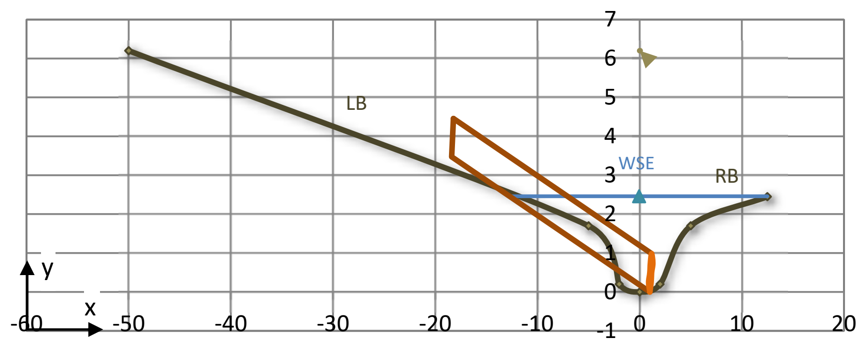
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

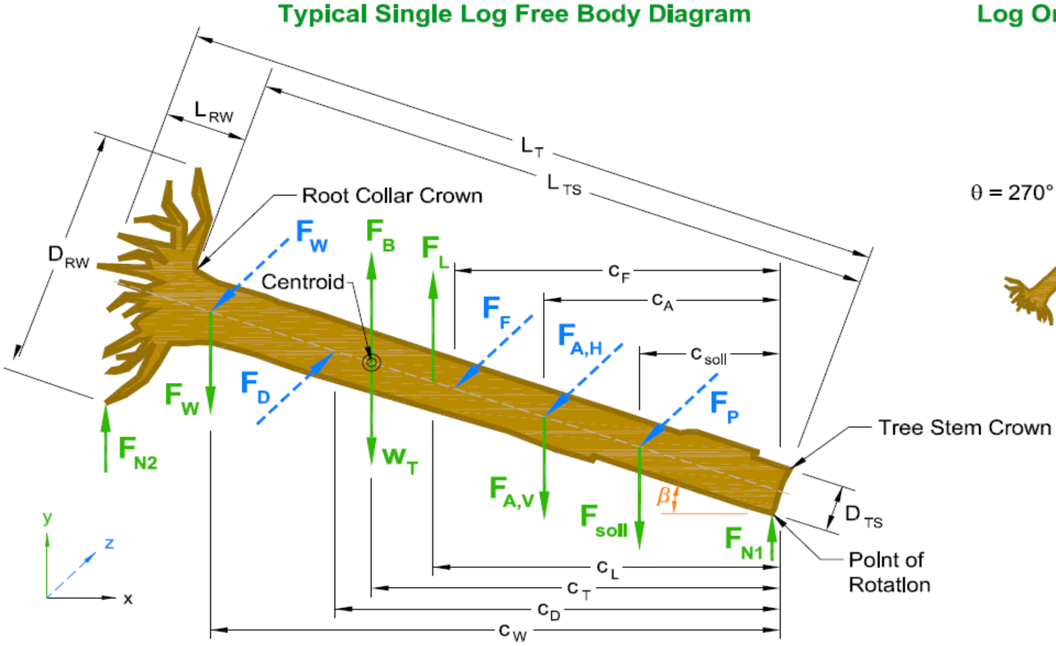


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

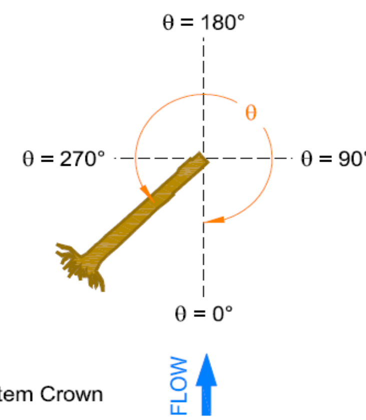
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	100.0	10.0	Root collar: Bottom	1.00	0.00	0.00	4.46	8.29

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	6.8	0.0	6.8	228	0
↓WS↑Thw	8.9	0.0	8.9	299	555
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	555

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	555	↑
F_L (lbf)	0	
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	28	↑
FS_V	0.95	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.37	0.46	1.10	0.43	3.90	215

Horizontal Force Balance

F_D (lbf)	215	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	215	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.45	0.84	0
Bank	4.81	0	9.70	0.87	0
Total	-	0	12.15	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	13.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation:	Root Collar

Moment Force Balance

M_d (lbf)	6,965
M_r (lbf)	5,189
FS_M	0.75

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

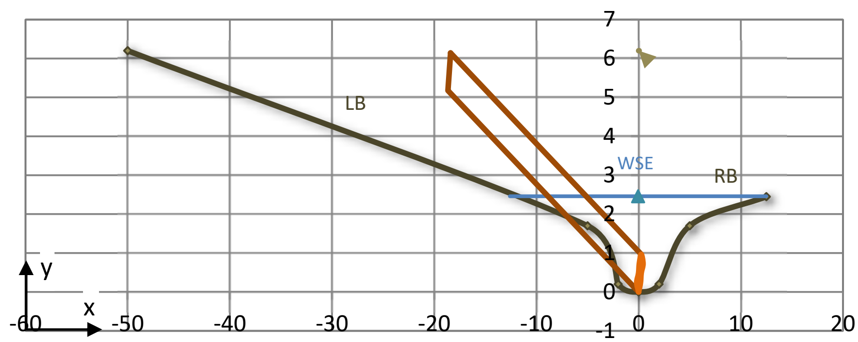
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

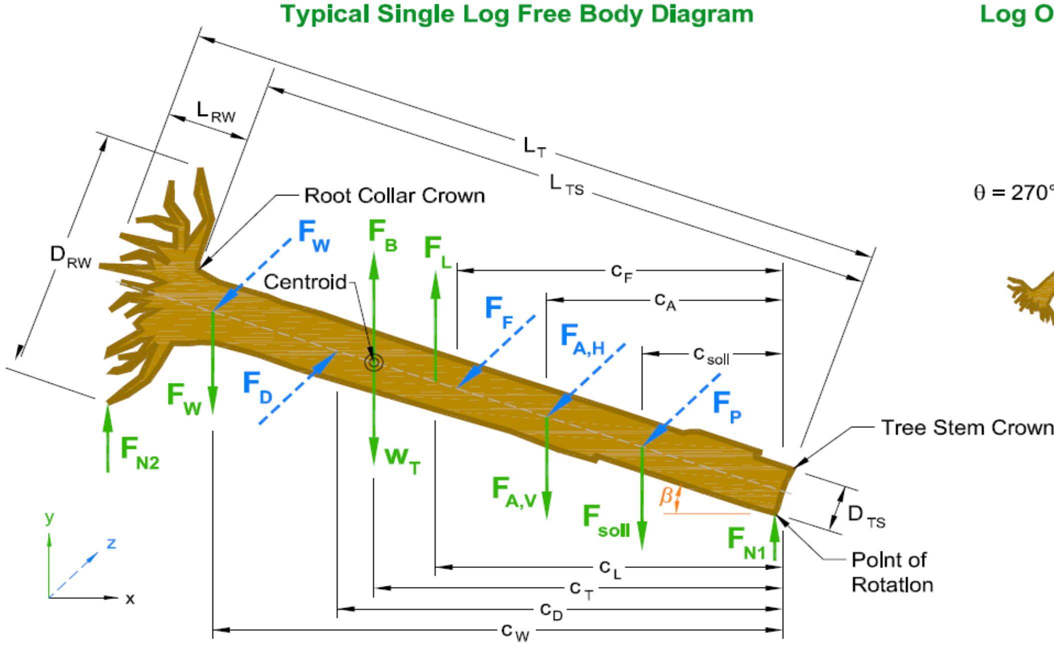


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

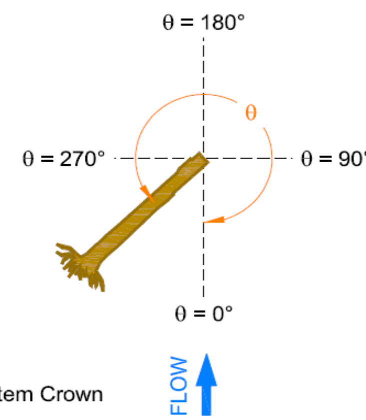
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	105.0	15.0	Root collar: Bottom	0.00	0.00	0.00	6.14	7.06

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	9.7	0.0	9.7	326	0
↓WS↑Thw	6.0	0.0	6.0	201	374
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	374

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	374 ↑
F_L (lbf)	0
W_T (lbf)	527 ↓
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	153 ↓
FS_V	1.41

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.31	0.46	1.13	0.43	3.36	158

Horizontal Force Balance

F_D (lbf)	158 →
F_P (lbf)	0
F_F (lbf)	131 ←
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	27 →
FS_H	0.83

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.05	0.84	56
Bank	4.81	0	2.60	0.87	74
Total	-	0	4.65	-	131

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	15.3	10.0	0.0	14.5	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	4,341
M_r (lbf)	6,604
FS_M	1.52

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

Cluster C Total Forces

Vertical Force Balance

ΣF_V (lbf)	4,976	↓

Horizontal Force Balance

ΣF_H (lbf)	4,991	←

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

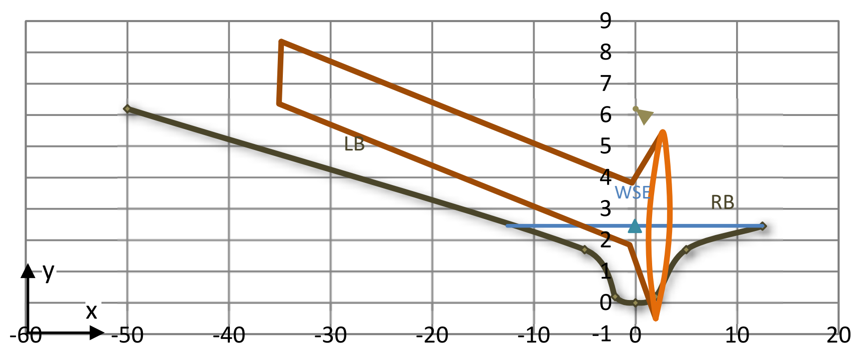
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	D Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

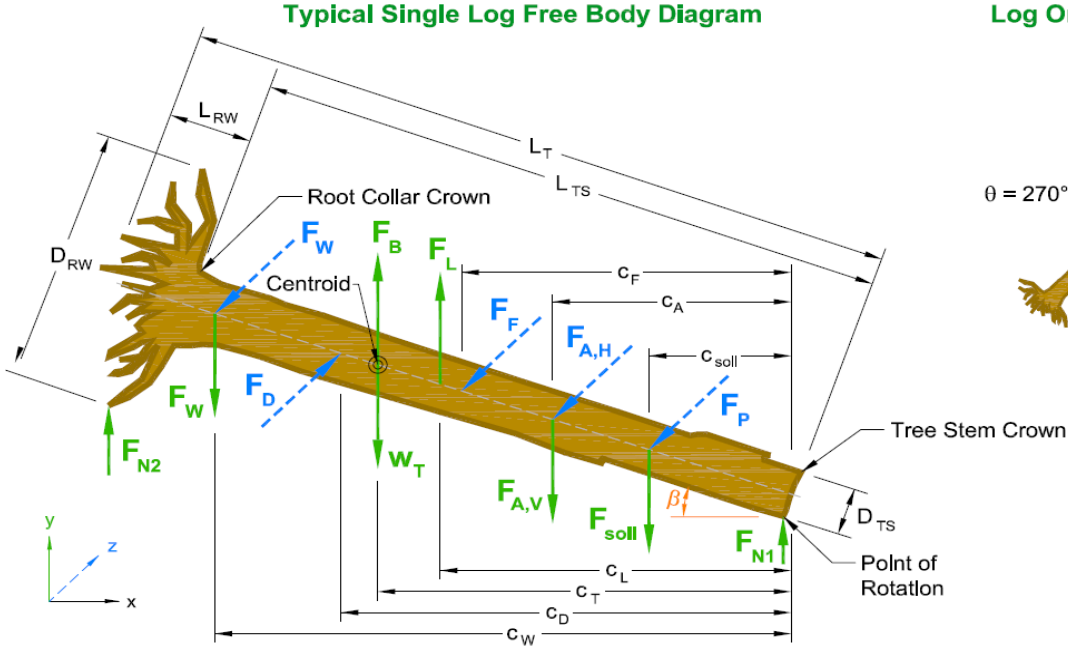


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

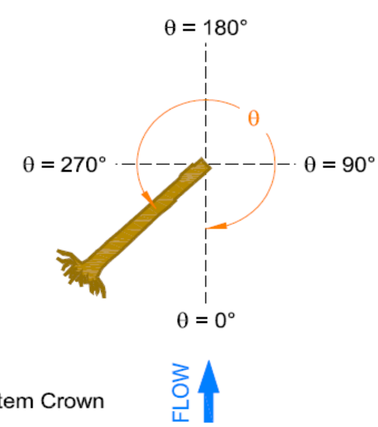
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	110.0	7.0	Rootwad: Bottom	2.00	-0.50	-0.50	8.34	79.64

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	114.6	17.6	132.2	4,434	0
↓WS↑Thw	1.7	14.8	16.5	553	1,030
↓Thalweg	0.0	0.2	0.2	8	14
Total	116.2	32.7	148.9	4,996	1,043

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,043
F_L (lbf)	0
W_T (lbf)	4,996
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	3,953
FS_V	4.79

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
3.52	0.33	1.00	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!
F_P (lbf)	0
F_F (lbf)	3,317
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	#NUM!
FS_H	#NUM!

#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	3,317
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	3,317

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	#NUM!	23.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation:	Rootwad

Moment Force Balance

M_d (lbf)	#NUM!
M_r (lbf)	372,969
FS_M	#NUM!

#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

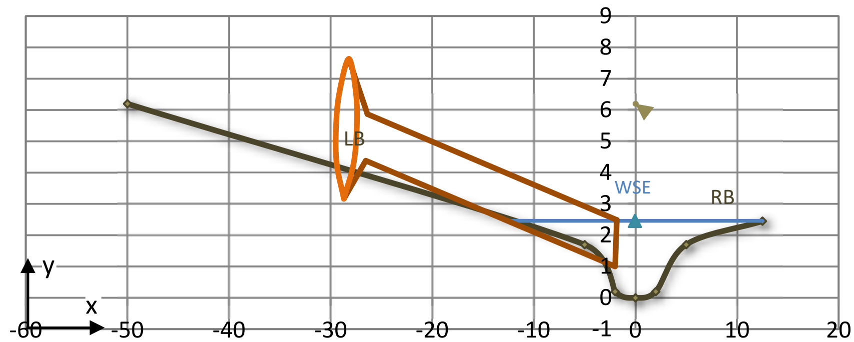
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	D Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

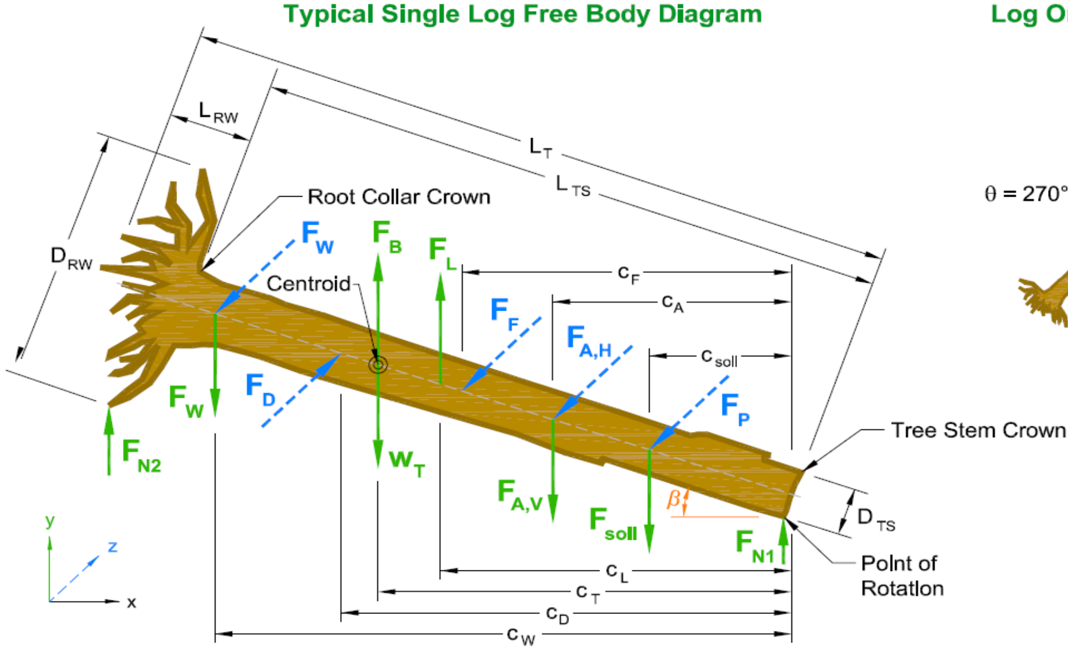


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

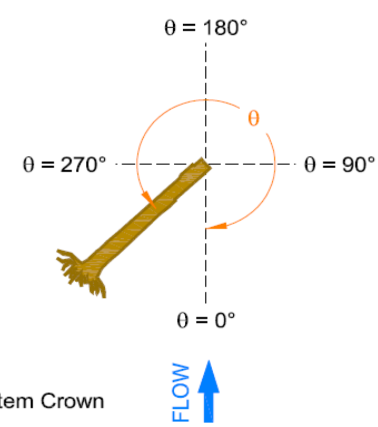
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	243.0	-7.0	Stem tip: Bottom	-2.00	1.00	1.00	7.63	40.10

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	38.7	13.8	52.4	1,759	0
↓WS↑Thw	10.4	0.0	10.4	348	648
↓Thalweg	0.0	0.0	0.0	0	0
Total	49.0	13.8	62.8	2,107	648

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	648
F_L (lbf)	0
W_T (lbf)	2,107
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,460
FS_V	3.25

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
1.77	0.38	1.06	0.00	#NUM!	#NUM!

Horizontal Force Balance

F_D (lbf)	#NUM!
F_P (lbf)	0
F_F (lbf)	1,261
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	#NUM!
FS_H	#NUM!

#NUM!

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	229
Bank	4.81	0	8.70	0.87	1,032
Total	-	0	10.70	-	1,261

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	0.0	#NUM!	17.2	0.0	7.1	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	#NUM!
M_r (lbf)	88,457
FS_M	#NUM!

#NUM!

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

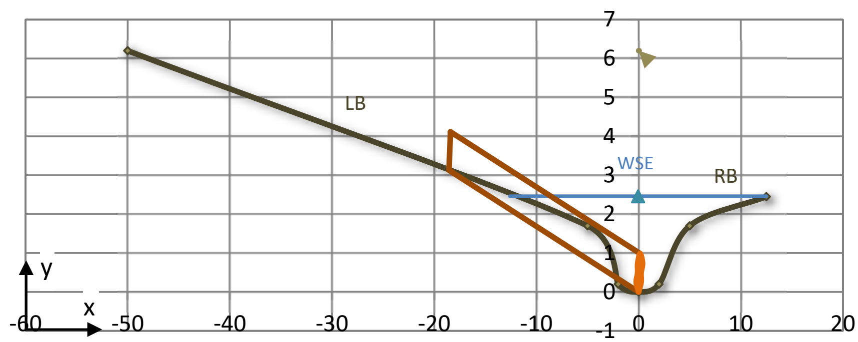
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	D Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

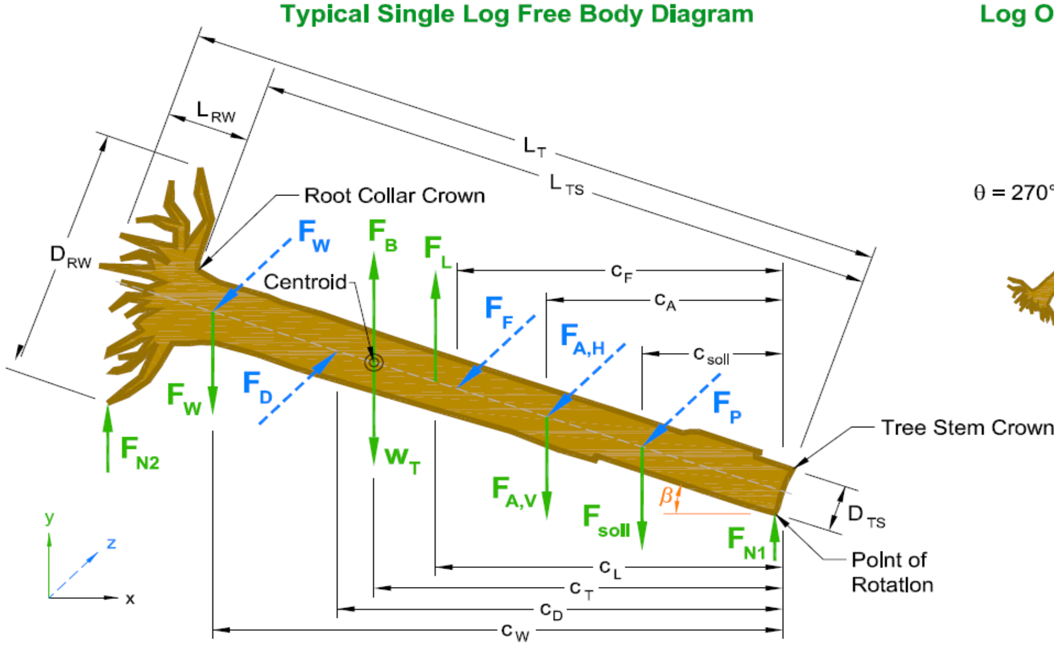


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

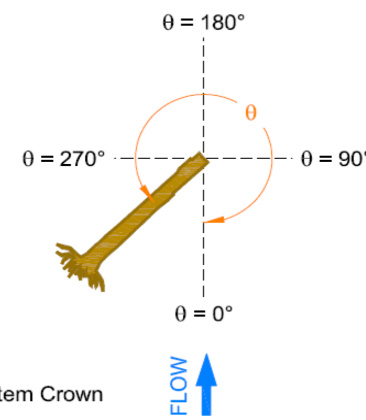
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	70.0	9.0	Root collar: Bottom	0.00	0.00	0.00	4.12	6.06

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	5.8	0.0	5.8	196	0
↓WS↑Thw	9.9	0.0	9.9	331	616
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	616

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	616
F_L (lbf)	0
W_T (lbf)	527
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	89
FS_V	0.86

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.27	0.46	1.12	0.43	2.94	118

Horizontal Force Balance

F_D (lbf)	118
F_P (lbf)	0
F_F (lbf)	0
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	118
FS_H	0.00

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.05	0.84	0
Bank	4.81	0	15.80	0.87	0
Total	-	0	17.85	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	12.2	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation:	Root Collar

Moment Force Balance

M_d (lbf)	7,002
M_r (lbf)	5,205
FS_M	0.74

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

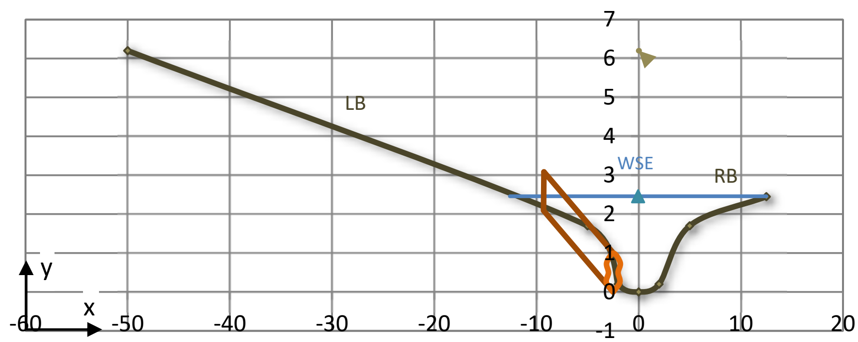
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Mox	Rootwad	Left bank	Straight	13+04	2.46	1.49	2.62

Multi-Log Structures	Layer	Log ID
	Stacked	D Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-5.00	1.70
Toe LB	-2.00	0.20
Thalweg	0.00	0.00
Toe RB	2.00	0.20
Top RB	5.00	1.70
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

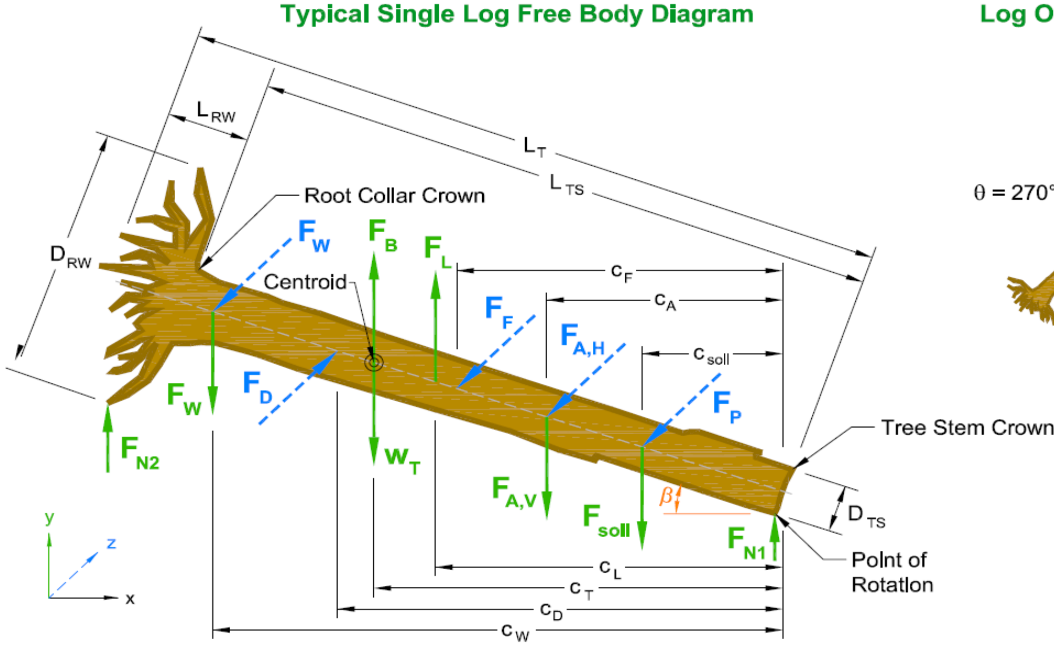


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

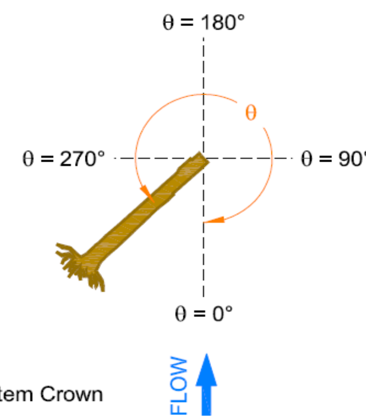
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	160.0	6.0	Root collar: Bottom	-2.50	0.00	0.00	3.09	2.42

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	1.4	0.0	1.4	46	0
↓WS↑Thw	14.3	0.0	14.3	481	895
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	895

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	895	↑
F_L (lbf)	0	
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	368	↑
FS_V	0.59	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.11	0.46	0.56	0.43	1.24	20

Horizontal Force Balance

F_D (lbf)	20	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	20	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	20.00	0.87	0
Total	-	0	22.00	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,099
M_r (lbf)	5,241
FS_M	0.58

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek

Spreadsheet developed by Michael Rafferty, P.E.

Cluster D Total Forces

Vertical Force Balance

Σ F_V (lbf)	3,496	↓

Horizontal Force Balance

Σ F_H (lbf)	#NUM!	✂✂✂

SR 8 MP 9.10 Unnamed Tributary to Mox Chehalis Creek
Notation, Units, and List of Symbols

Notation

Symbol	Description	Unit
A_W	Wetted area of channel at design discharge	ft^2
A_{Tp}	Projected area of wood in plane perpendicular to flow	ft^2
c_D	Centroid of the drag force along log axis	ft
c_{Am}	Centroid of a mechanical anchor along log axis	ft
c_{Ar}	Centroid of a ballast boulder along log axis	ft
c_{Asoil}	Centroid of the added ballast soil along log axis	ft
$c_{F\&N}$	Centroid of friction and normal forces along log axis	ft
c_L	Centroid of the lift force along log axis	ft
c_P	Centroid of the passive soil force along log axis	ft
c_{soil}	Centroid of the vertical soil forces along log axis	ft
$c_{T,B}$	Centroid of the buoyancy force along log axis	ft
$c_{T,W}$	Centroid of the log volume along log axis	ft
c_{WI}	Centroid of a wood interaction force along log axis	ft
C_{Lrock}	Coefficient of lift for submerged boulder	-
C_{LT}	Effective coefficient of lift for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_D*	Effective coefficient of drag for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_W	Wave drag coefficient of submerged tree	-
$d_{b,avg}$	Average buried depth of log	ft
$d_{b,max}$	Maximum buried depth of log	ft
d_w	Maximum flow depth at design discharge in reach	ft
D_{50}	Median grain size in millimeters (SI units)	mm
D_r	Equivalent diameter of boulder	ft
D_{RW}	Assumed diameter of rootwad	ft
D_{TS}	Nominal diameter of tree stem (DBH)	ft
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-
e	Void ratio of soils	-
$F_{A,H}$	Total horizontal load capacity of anchor techniques	lbf
$F_{A,HP}$	Passive soil pressure applied to log from soil ballast	lbf
$F_{A,Hr}$	Horizontal resisting force on log from boulder	lbf
F_{Am}	Load capacity of mechanical anchor	lbf
$F_{A,V}$	Total vertical load capacity of anchor techniques	lbf
$F_{A,Vr}$	Vertical resisting force on log from boulder	lbf
$F_{A,Vsoil}$	Vertical soil loading on log from added ballast soil	lbf
F_B	Buoyant force applied to log	lbf
F_D	Drag forces applied to log	lbf
$F_{D,r}$	Drag forces applied to boulder	lbf
F_F	Friction force applied to log	lbf
F_H	Resultant horizontal force applied to log	lbf
F_L	Lift force applied to log	lbf
$F_{L,r}$	Lift force applied to boulder	lbf
F_P	Passive soil pressure force applied to log	lbf
F_{soil}	Vertical soil loading on log	lbf
$F_{W,H}$	Horizontal forces from interactions with other logs	lbf
$F_{W,V}$	Vertical forces from interactions with other logs	lbf

Notation (continued)

Symbol	Description	Unit
F_V	Resultant vertical force applied to log	lbf
Fr_L	Log Froude number	-
FS_V	Factor of Safety for Vertical Force Balance	-
FS_H	Factor of Safety for Horizontal Force Balance	-
FS_M	Factor of Safety for Moment Force Balance	-
g	Gravitational acceleration constant	ft/s^2
K_P	Coefficient of Passive Earth Pressure	-
$L_{T,em}$	Total embedded length of log	ft
L_{RW}	Assumed length of rootwad	ft
L_T	Total length of tree (including rootwad)	ft
L_{Tf}	Length of log in contact with bed or banks	ft
L_{TS}	Length of tree stem (not including rootwad)	ft
$L_{TS,ex}$	Exposed length of tree stem	ft
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-
M_d	Driving moment about embedded tip	lbf
M_r	Driving moment about embedded tip	lbf
N	Blow count of standard penetration test	-
p_o	Porosity of soil volume	-
Q_{des}	Design discharge	cfs
R	Radius	ft
R_c	Radius of curvature at channel centerline	ft
SG_r	Specific gravity of quartz particles	-
SG_T	Specific gravity of tree	-
u_{avg}	Average velocity of cross section in reach	ft/s
u_{des}	Design velocity	ft/s
u_m	Adjusted velocity at outer meander bend	ft/s
V_{dry}	Volume of soils above stage level of design flow	ft^3
V_{sat}	Volume of soils below stage level of design flow	ft^3
V_{soil}	Total volume of soils over log	ft^3
V_{RW}	Volume of rootwad	ft^3
V_S	Volume of solids in soil (void ratio calculation)	ft^3
V_T	Total volume of log	ft^3
V_{TS}	Total volume of tree	ft^3
V_V	Volume of voids in soil	ft^3
V_{Adry}	Volume of ballast above stage of design flow	ft^3
V_{Awet}	Volume of ballast below stage of design flow	ft^3
$V_{r,dry}$	Volume of boulder above stage of design flow	ft^3
$V_{r,wet}$	Volume of boulder below stage of design flow	ft^3
W_{BF}	Bankfull width at structure site	ft
W_r	Effective weight of boulder	lbf
W_T	Total log weight	lbf
x	Horizontal coordinate (distance)	ft
y	Vertical coordinate (elevation)	ft
$y_{T,max}$	Minimum elevation of log	ft
$y_{T,min}$	Maximum elevation of log	ft

Greek Symbols

Symbol	Description	Unit
β	Tilt angle from stem tip to vertical	deg
γ_{bank}	Dry specific weight of bank soils	lb/ft^3
$\gamma_{bank,sat}$	Saturated unit weight of bank soils	lb/ft^3
γ'_{bank}	Effective buoyant unit weight of bank soils	lb/ft^3
γ_{bed}	Dry specific weight of stream bed substrate	lb/ft^3
γ'_{bed}	Effective buoyant unit weight of stream bed substrate	lb/ft^3
γ_{rock}	Dry unit weight of boulders	lb/ft^3
γ_s	Dry specific weight of soil	lb/ft^3
γ'_s	Effective buoyant unit weight of soil	lb/ft^3
γ_{Td}	Air-dried unit weight of tree (12% MC basis)	lb/ft^3
γ_{Tgr}	Green unit weight of tree	lb/ft^3
γ_w	Specific weight of water at 50ºF	lb/ft^3
η	Rootwad porosity	-
θ	Rootwad (or large end of log) orientation to flow	deg
μ	Coefficient of friction	-
ν	Kinematic viscosity of water at 50ºF	ft/s^2
Σ	Sum of forces	-
ϕ_{bank}	Internal friction angle of bank soils	deg
ϕ_{bed}	Internal friction angle of stream bed substrate	deg

Units

Notation	Description
cfs	Cubic feet per second
ft	Feet
lb	Pound
lbf	Pounds force
kg	Kilograms
m	Meters
mm	Millimeters
s	Seconds
yr	Year

Abbreviations

Notation	Description
ARI	Average return interval
Avg	Average
DBH	Diameter at breast height
deg	Degrees
Dia	Diameter
Dist	Distance
D/S	Downstream
ELJ	Engineered log jam
Ex	Example
Fldpln	Floodplain
H&H	Hydrologic and hydraulic
ID	Identification
i.e.	That is
LB	Left bank
LW	Large wood
Max	Maximum
MC	Moisture content
Min	Minimum
ML	Multi-log
SL	Single log
N/A	Not applicable
no	Number
Pt	Point
rad	Radians
RB	Right bank
RW	Rootwad
SL	Single log
Thw	Thalweg (lowest elevation in channel bed)
Typ	Typical
U.S.	United States
WS	Water surface
WSE	Water surface elevation
↑	Above
↓	Below

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name: 990773

Stream Name:

Drainage Area: 65 ac

Projected mean percent change in bankfull flow:

2040s: 18.7%

2080s: 24.8%

Projected mean percent change in bankfull width:

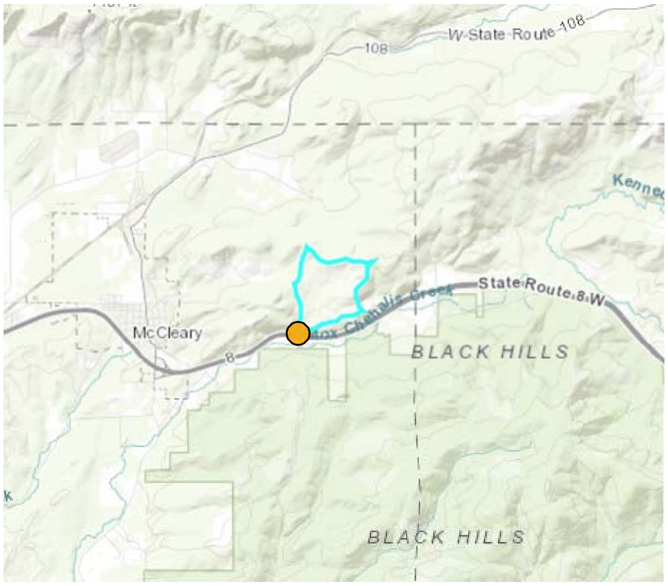
2040s: 9%

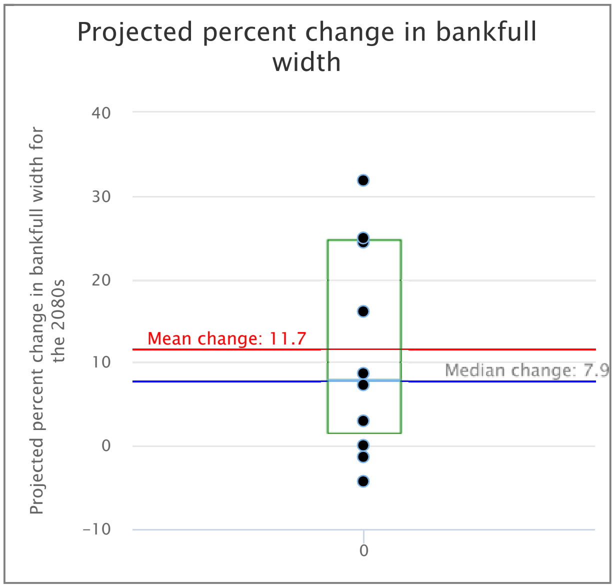
2080s: 11.7%

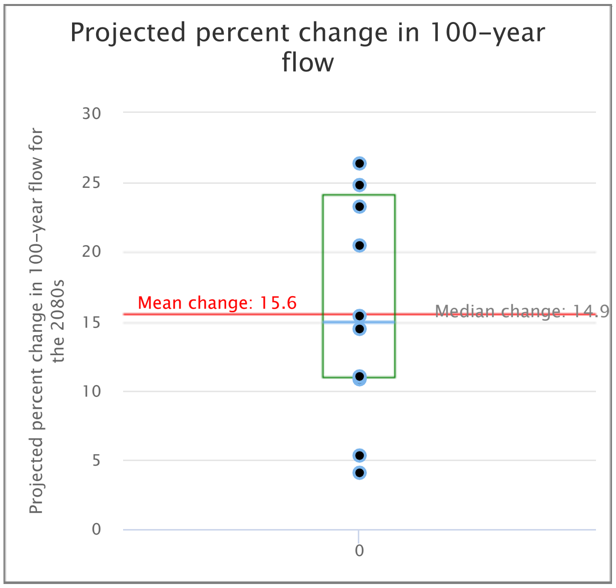
Projected mean percent change in 100-year flood:

2040s: 10.3%

2080s: 15.6%







Black dots are projections from 10 separate models

Appendix H: SRH-2D Model Results

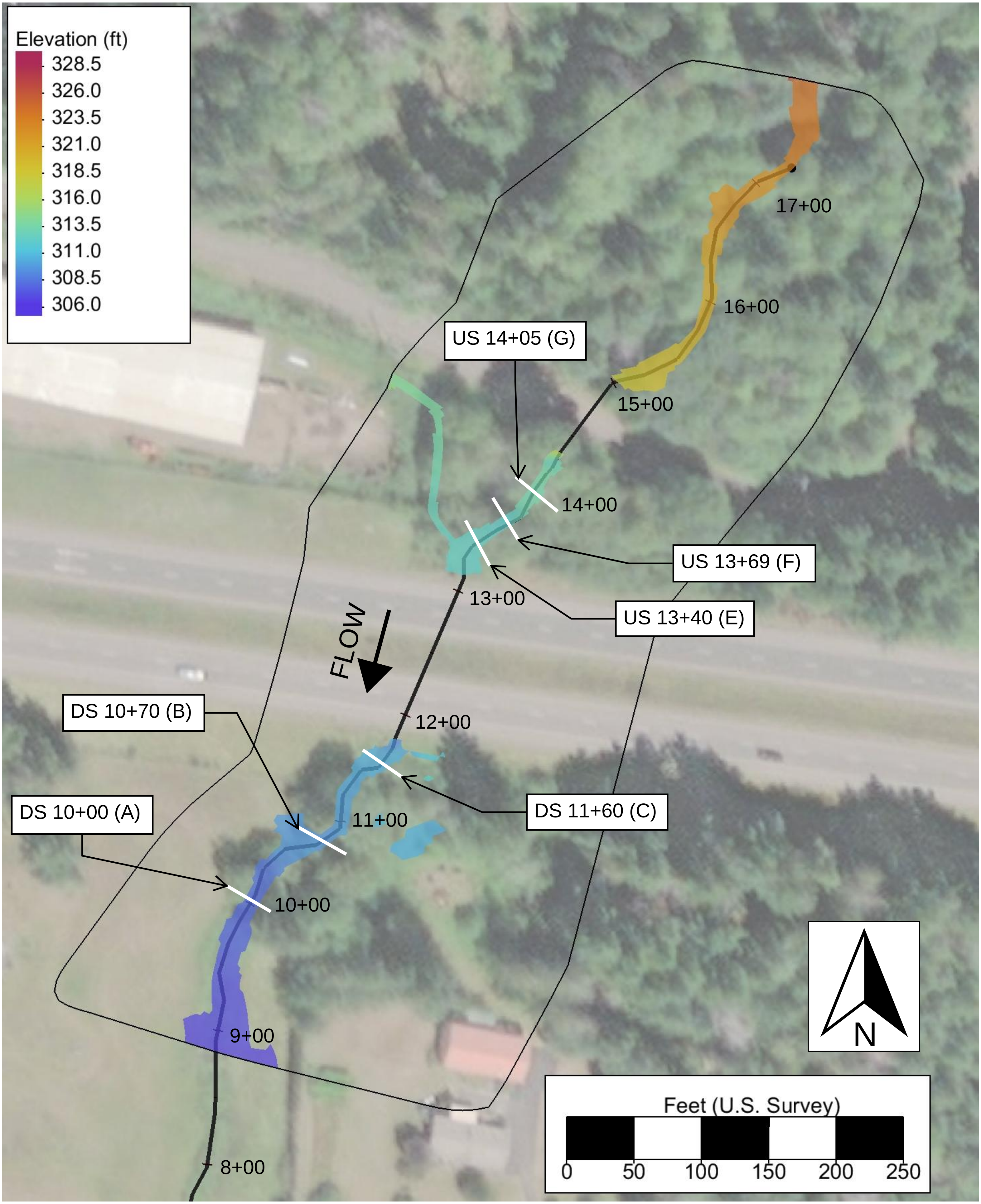


Figure H.1: Existing conditions 2-year water surface elevation

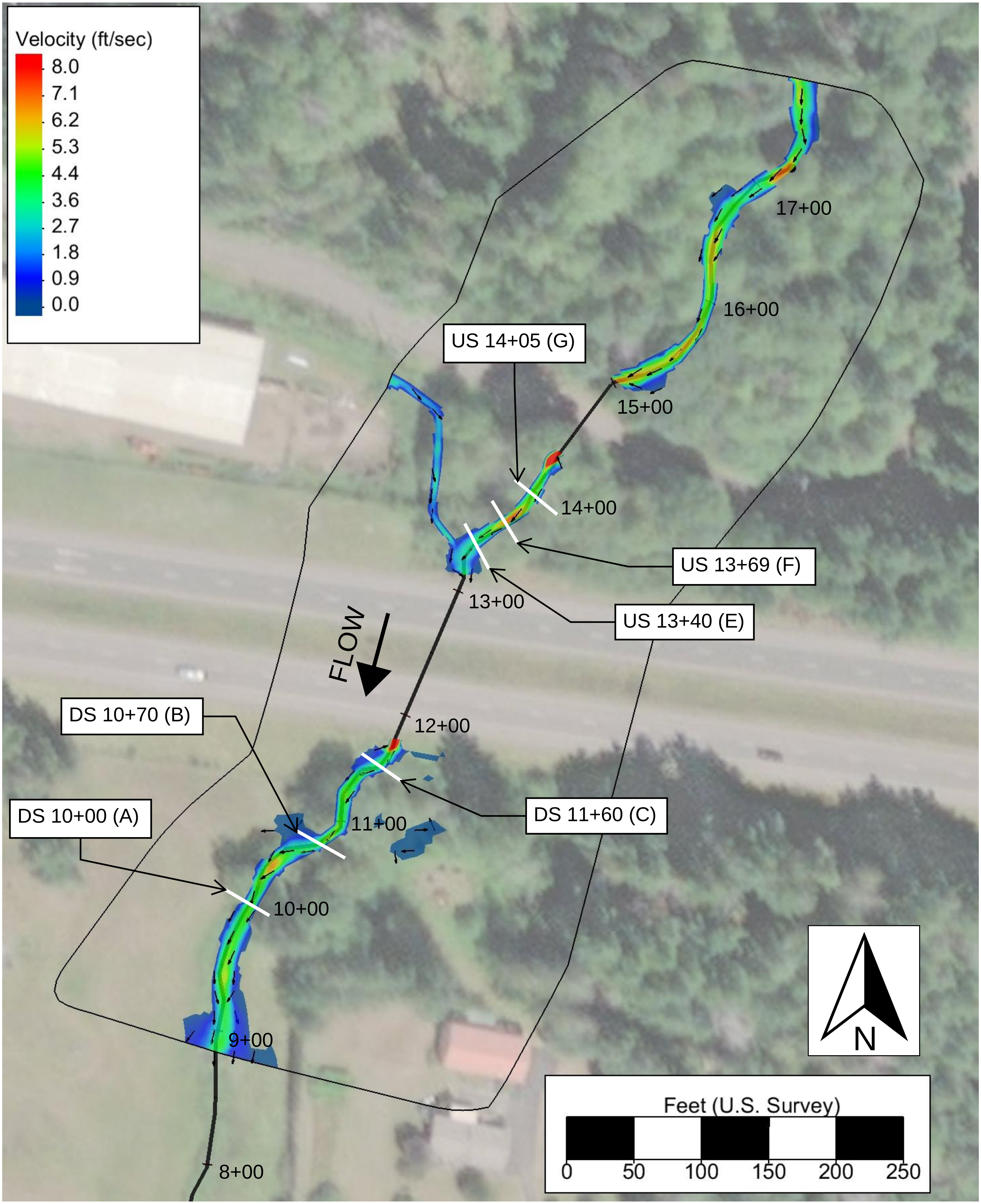


Figure H.2: Existing conditions 2-year velocity

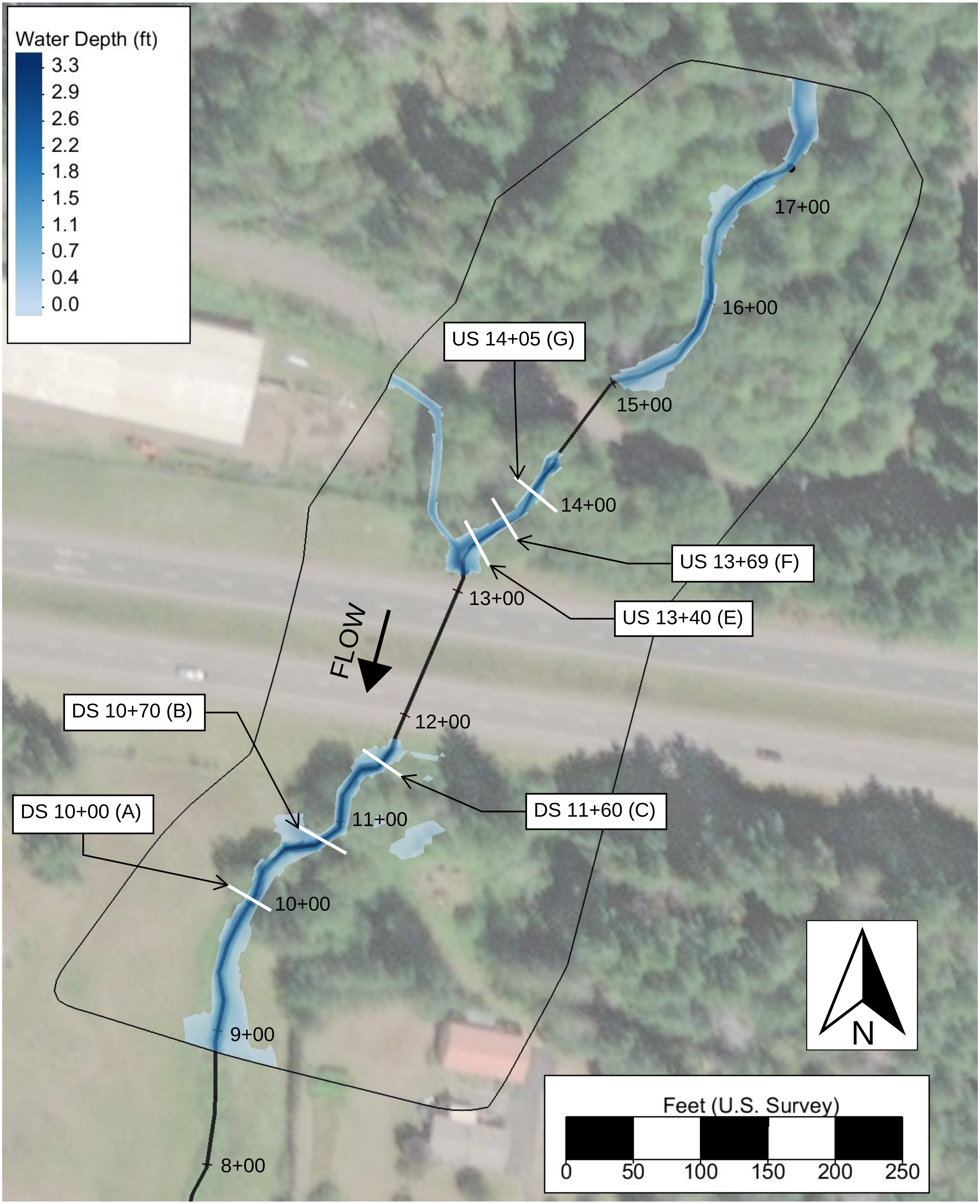


Figure H.3: Existing conditions 2-year water depth

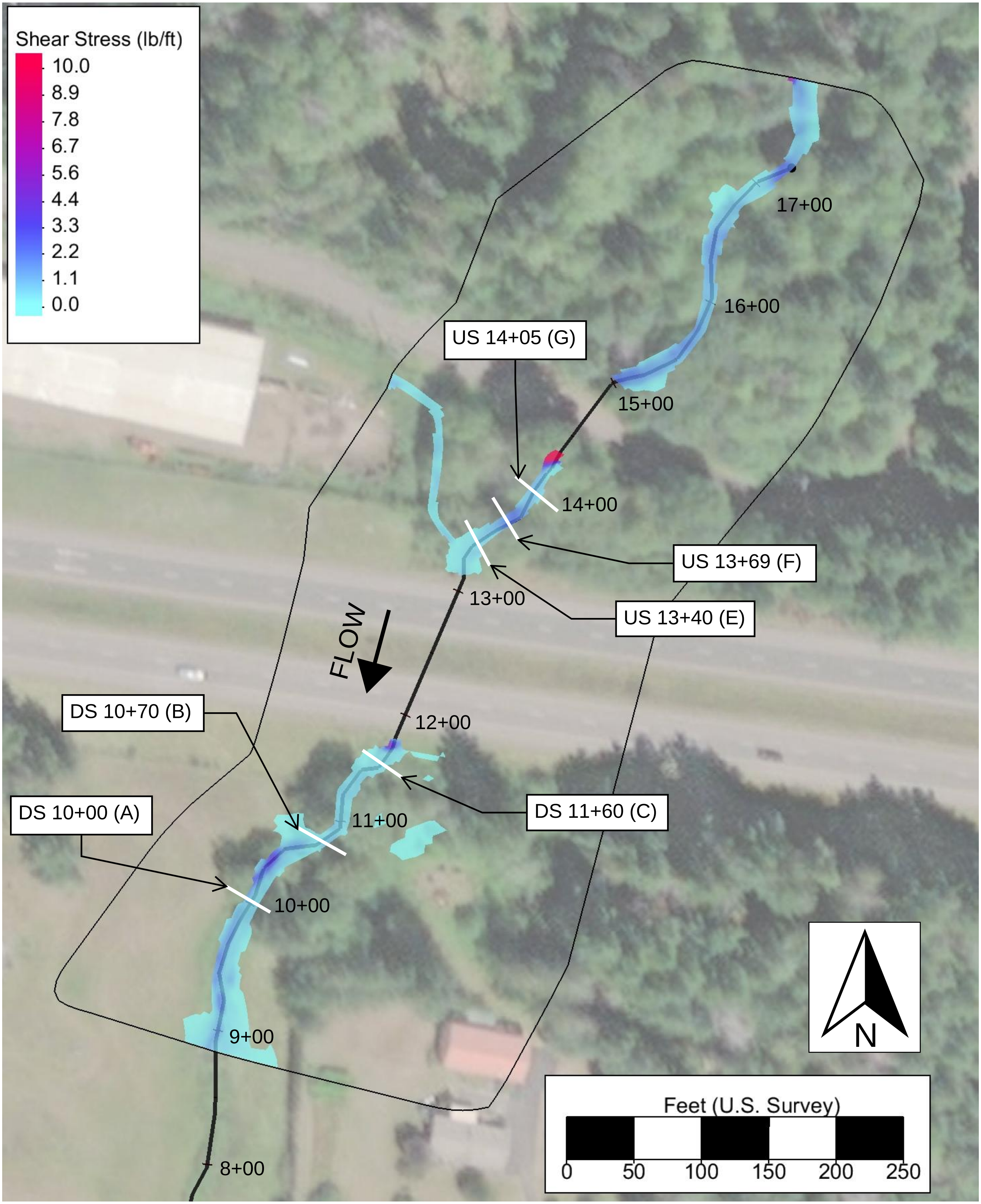


Figure H.4: Existing conditions 2-year shear stress

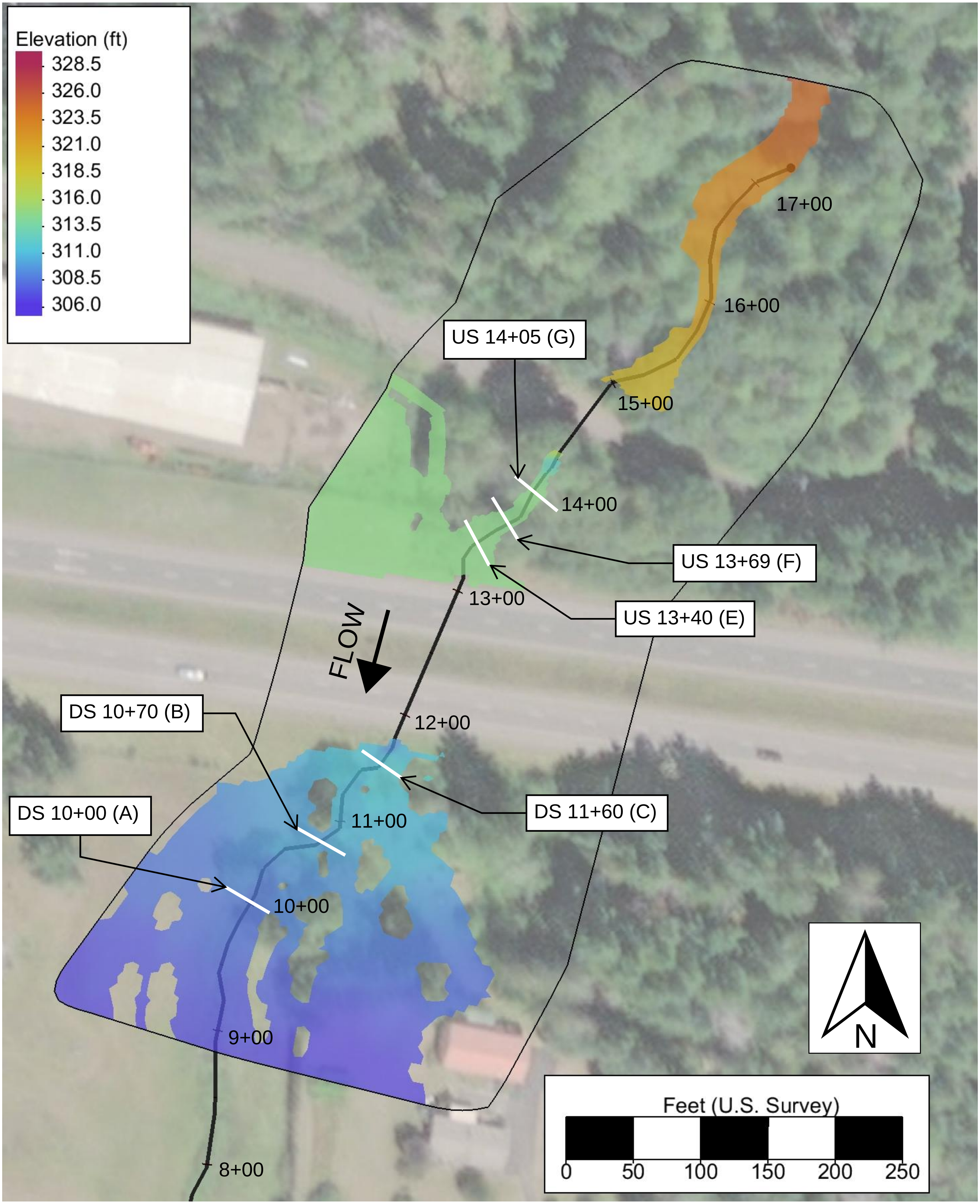


Figure H.5: Existing conditions 100-year water surface elevation

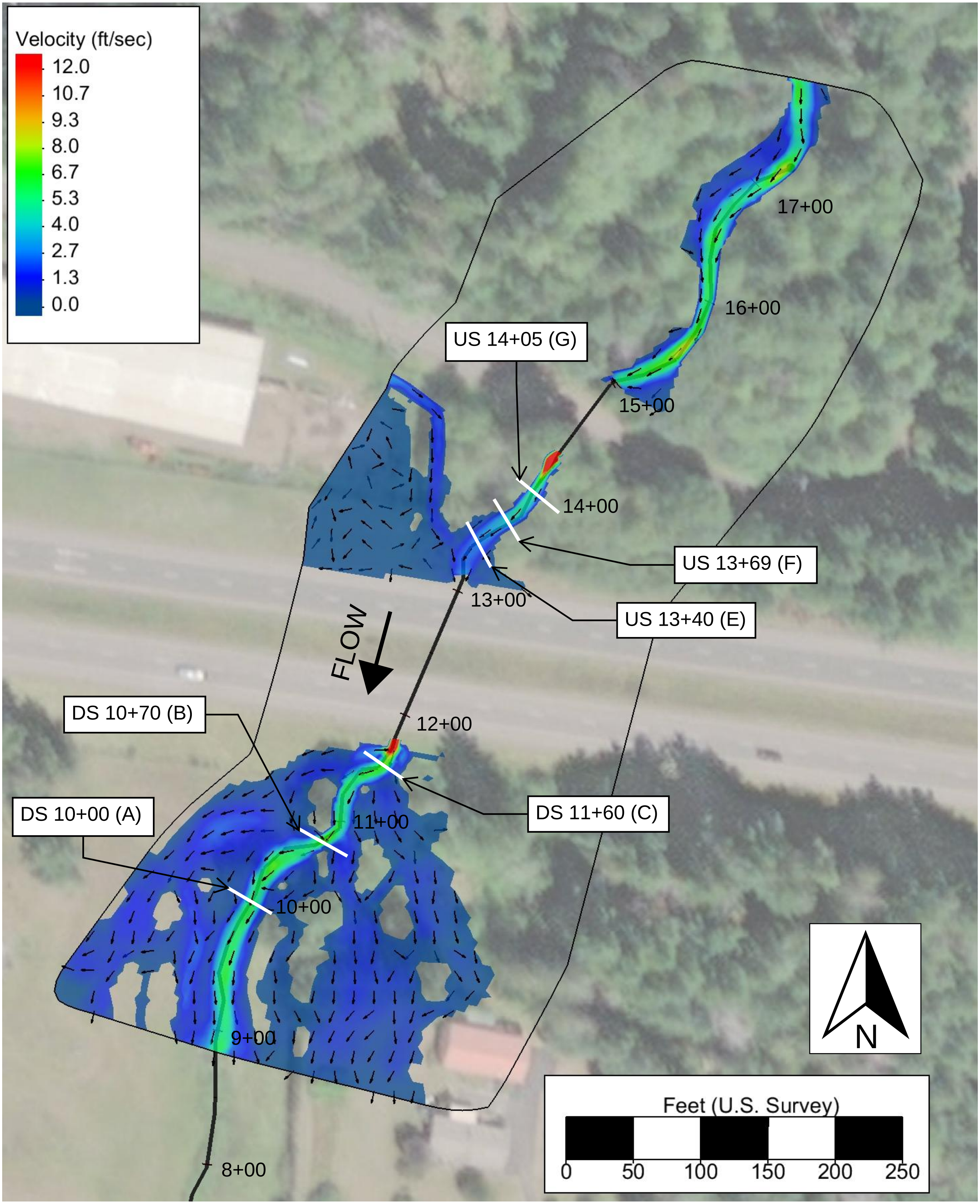


Figure H.6: Existing conditions 100-year velocity

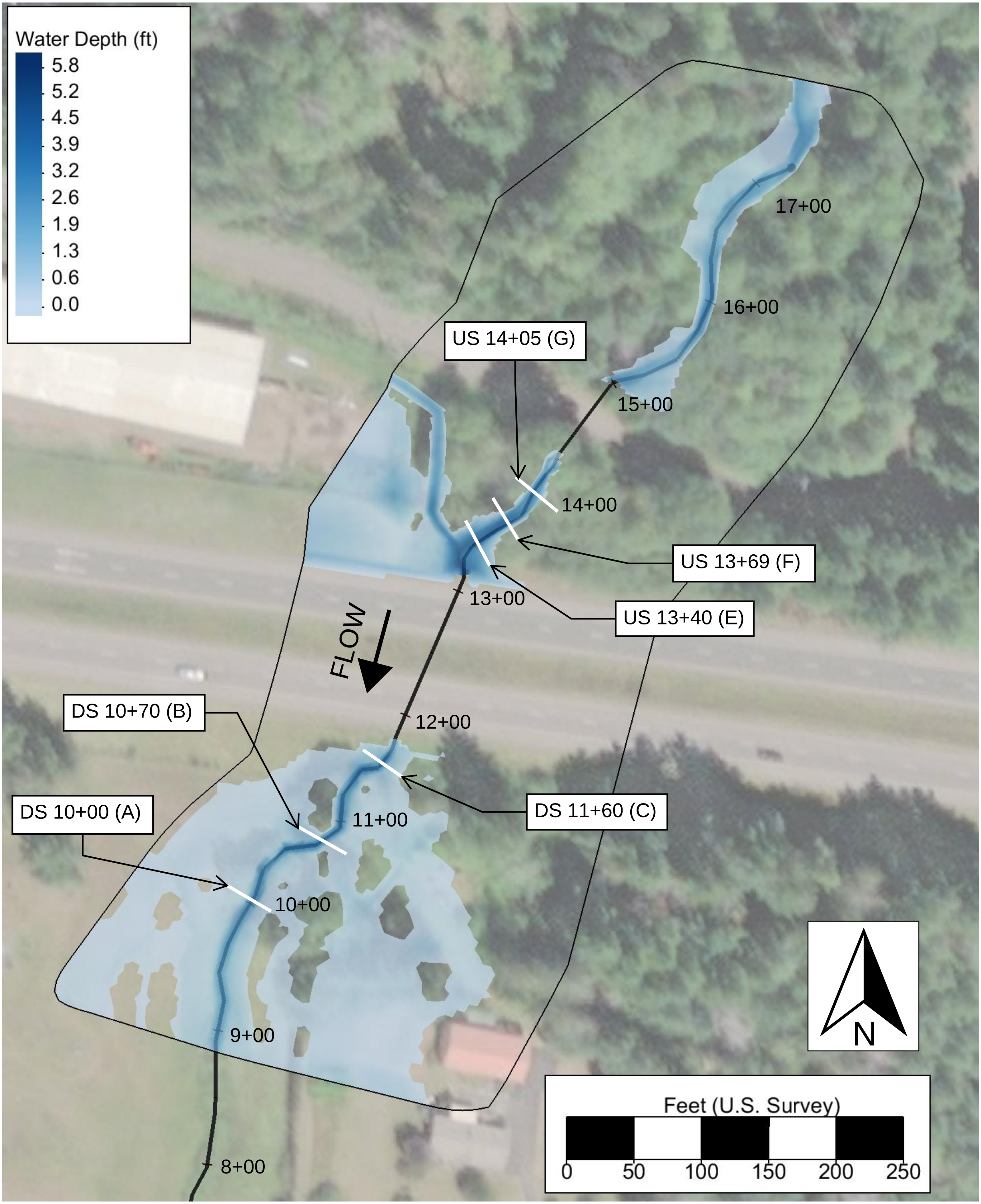


Figure H.7: Existing conditions 100-year water depth

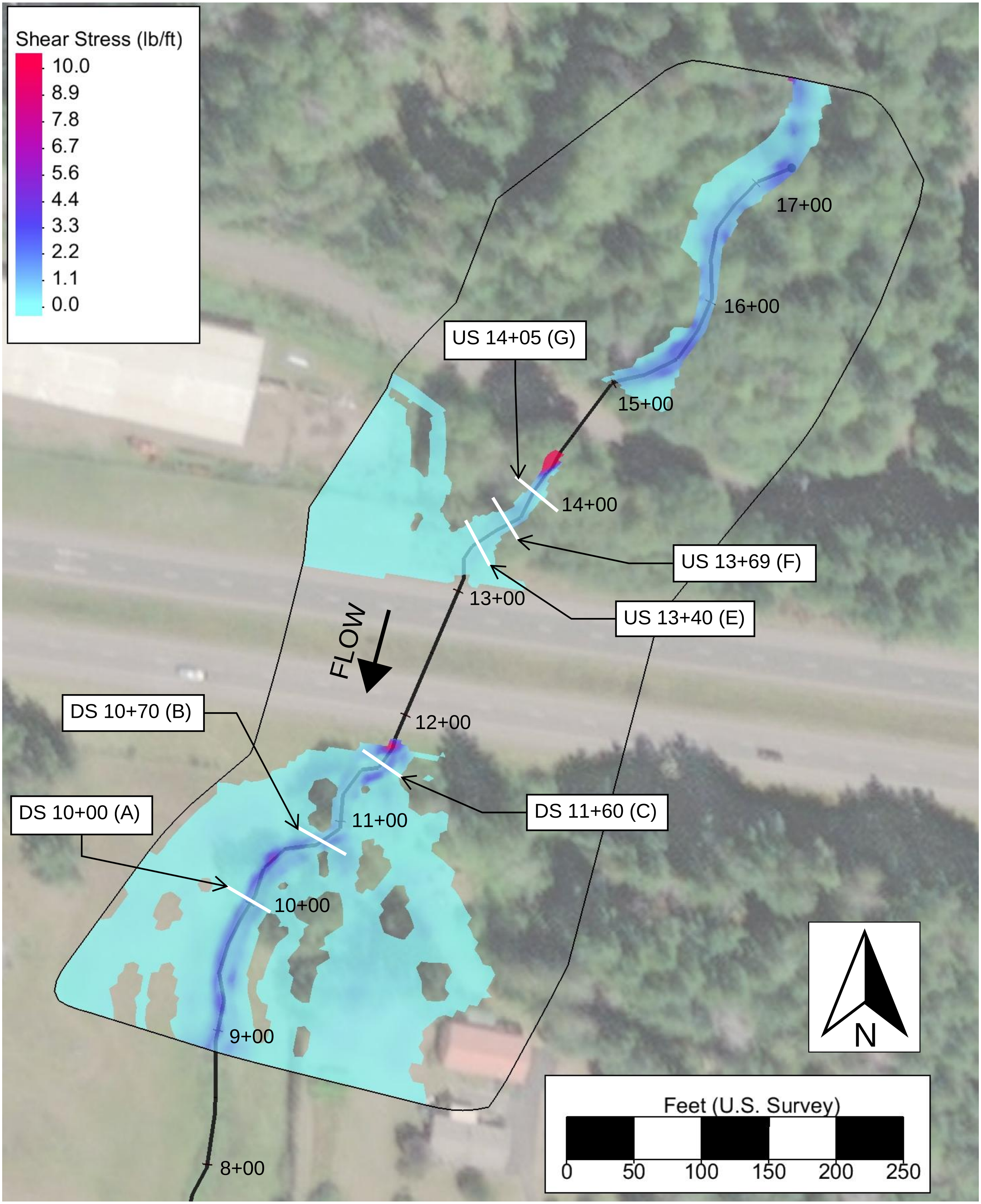


Figure H.8: Existing conditions 100-year shear stress

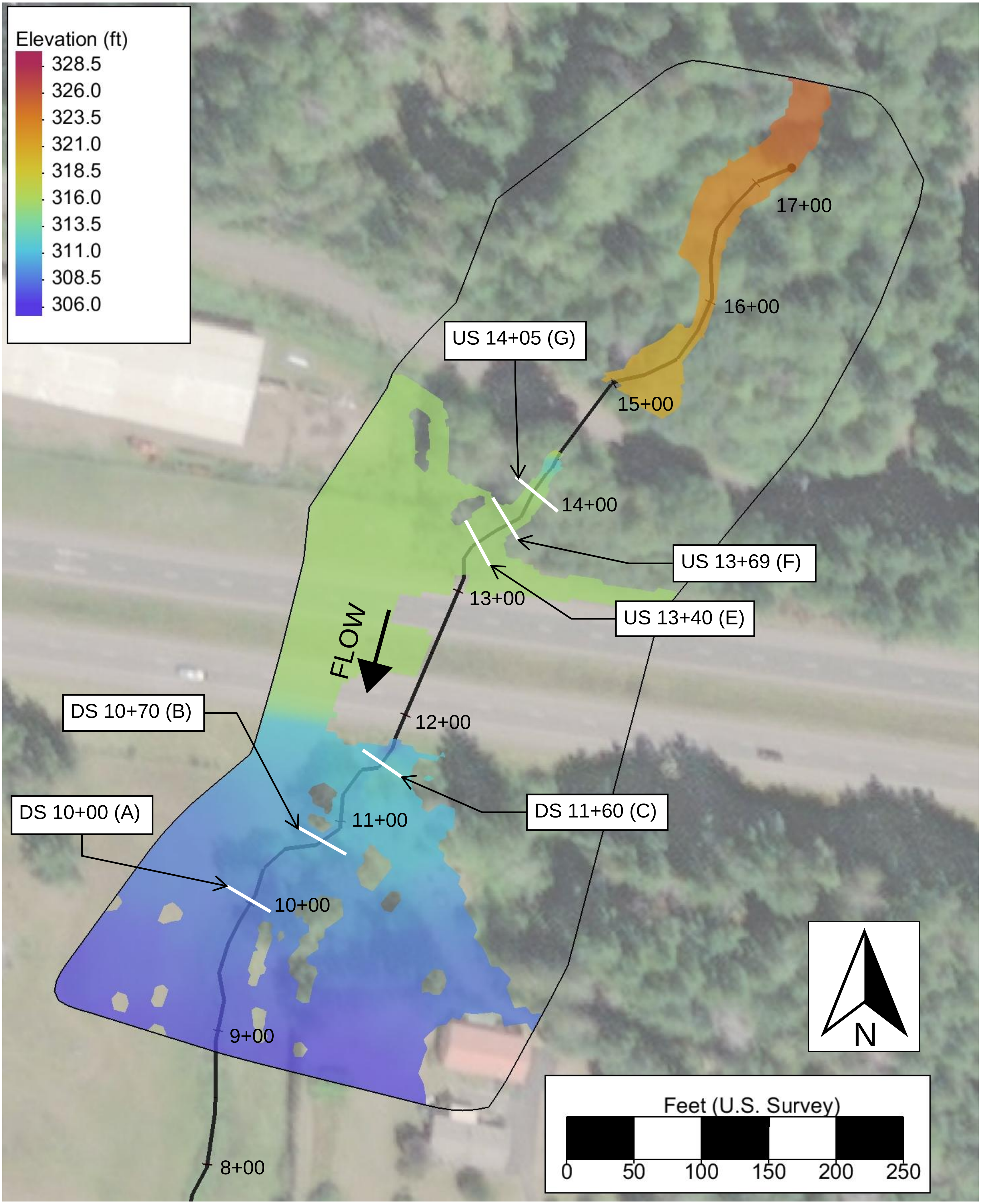


Figure H.9: Existing conditions 500-year water surface elevation

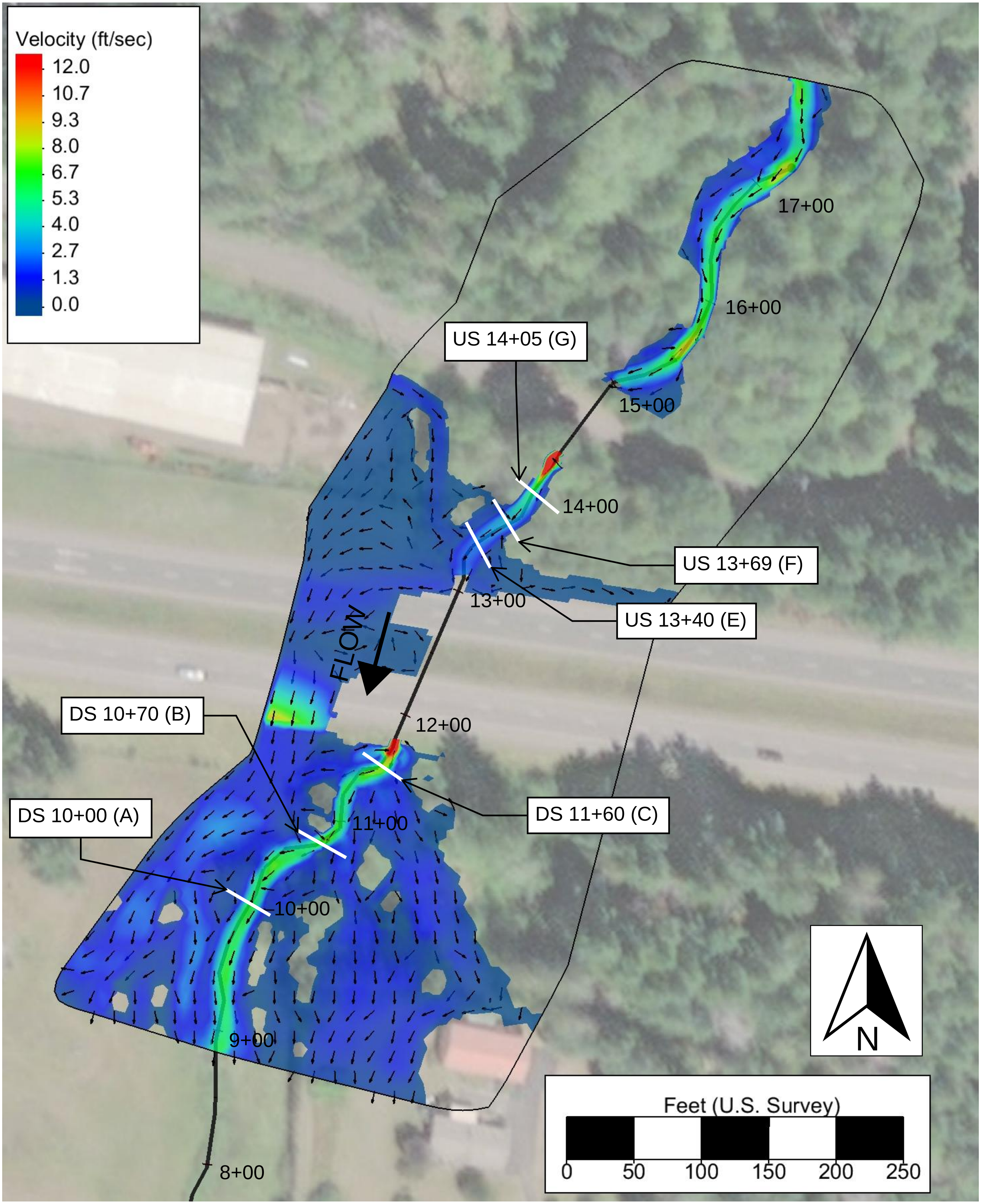


Figure H.10: Existing conditions 500-year velocity

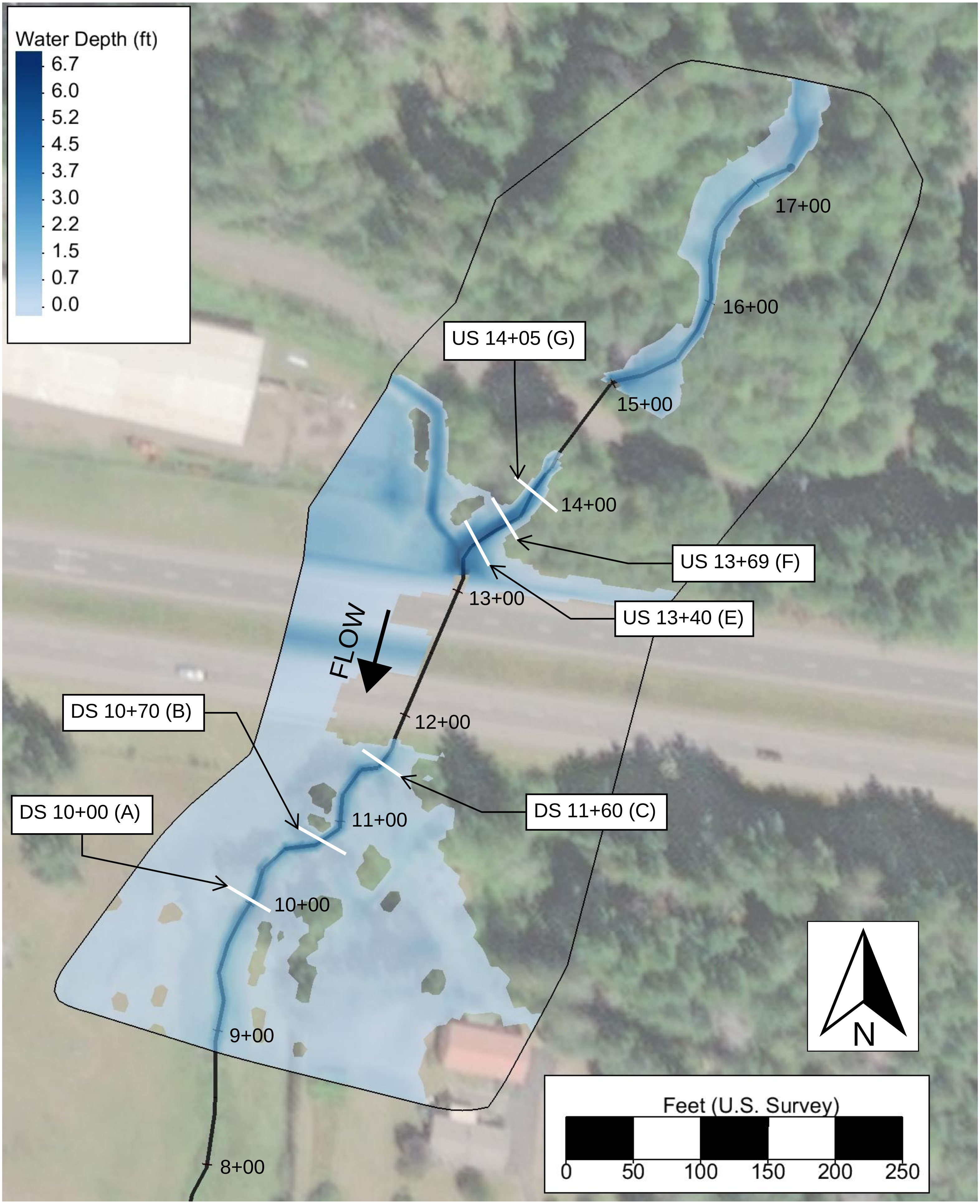


Figure H.11: Existing conditions 500-year water depth

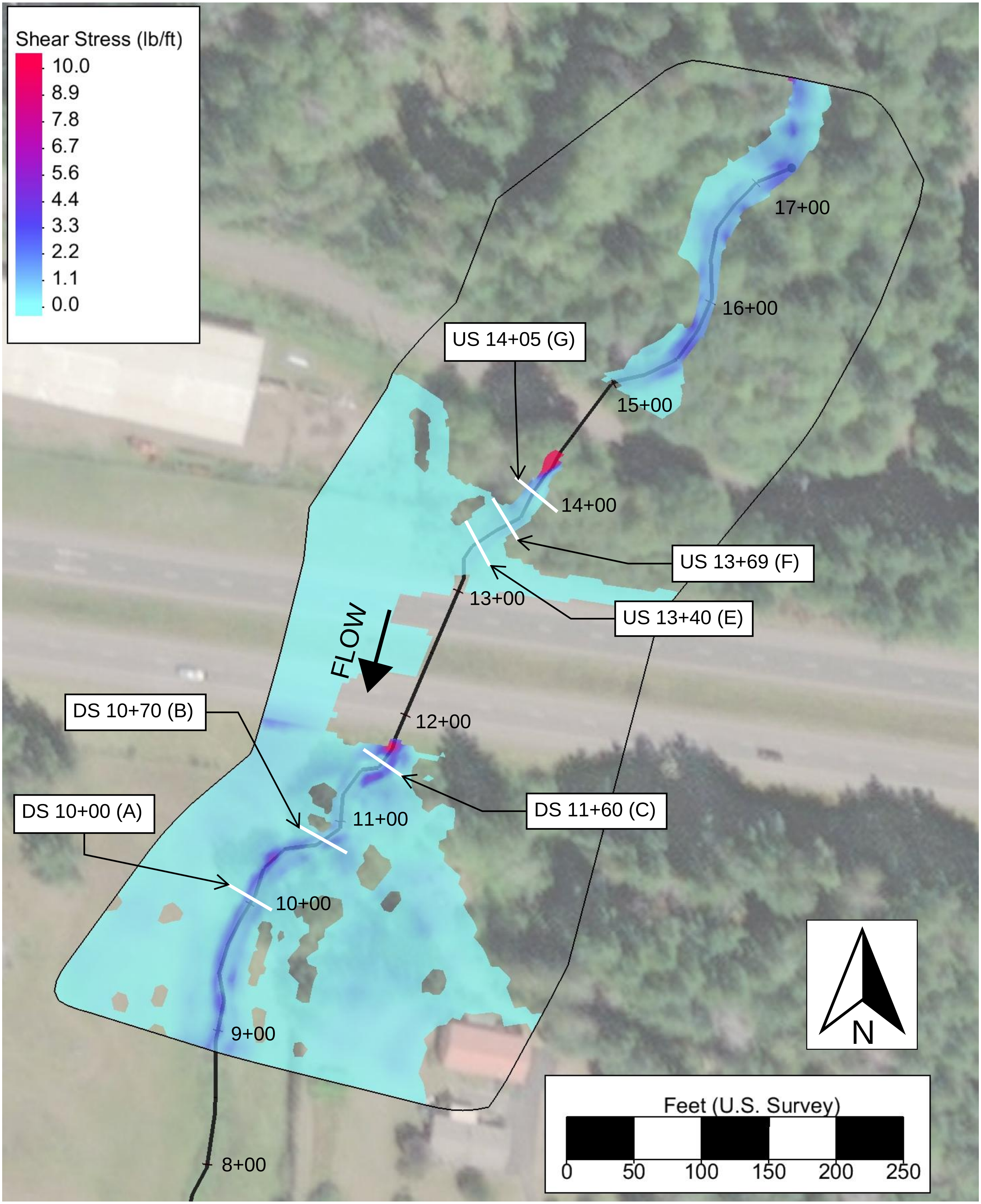


Figure H.12: Existing conditions 500-year water shear stress

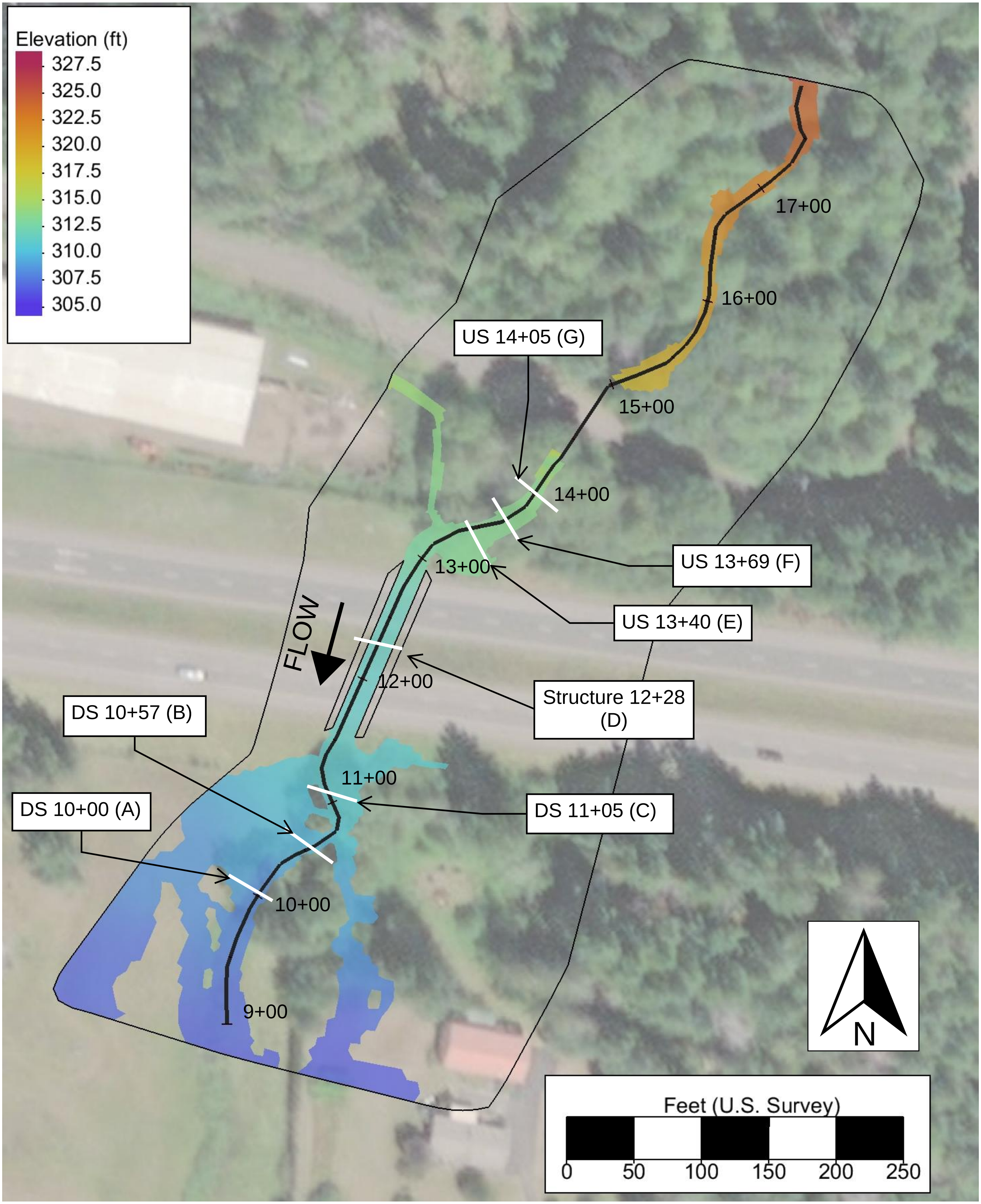


Figure H.13: Proposed conditions 2-year water surface elevation

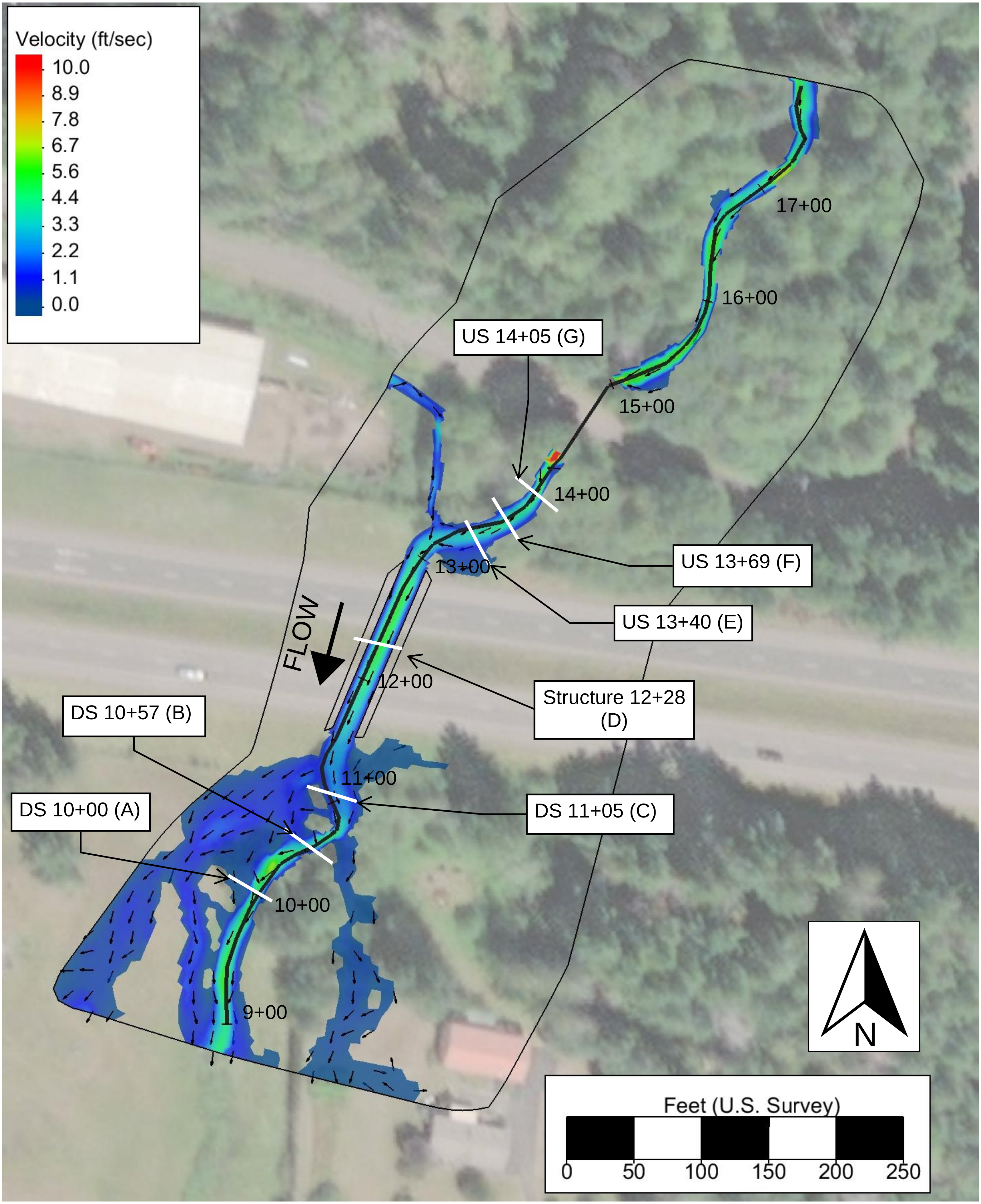


Figure H.14: Proposed conditions 2-year velocity

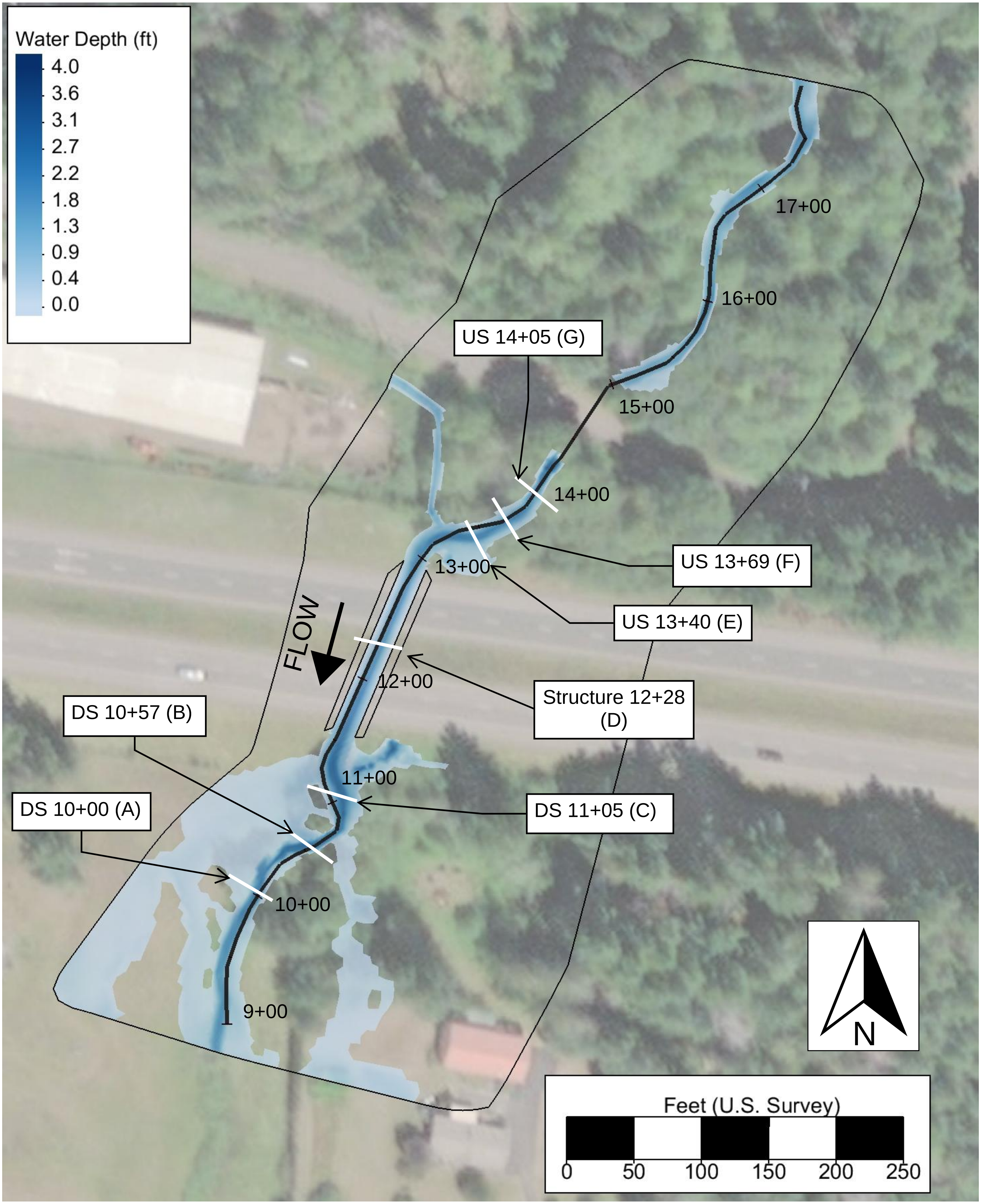


Figure H.15: Proposed conditions 2-year water depth

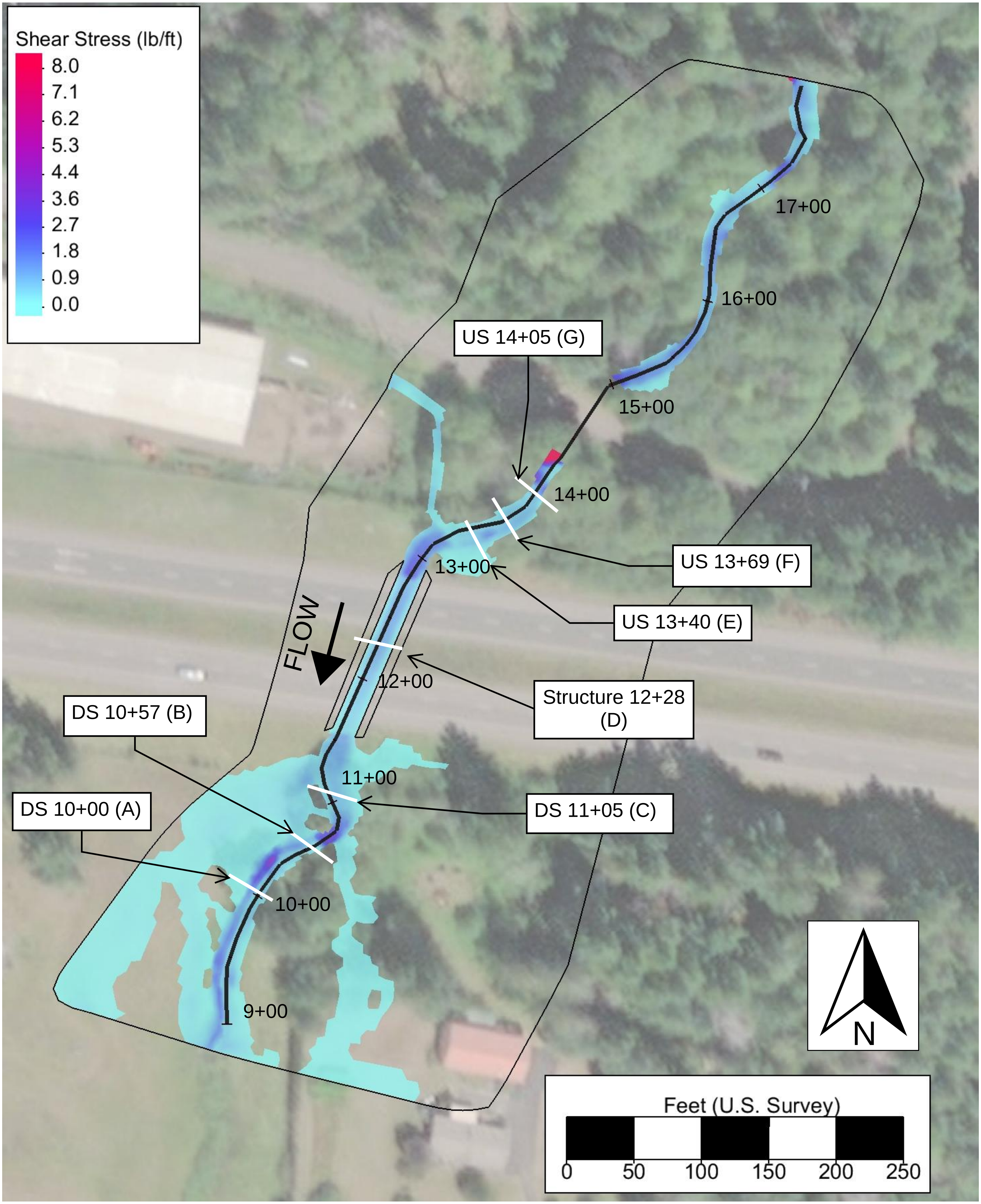


Figure H.16: Proposed conditions 2-year shear stress

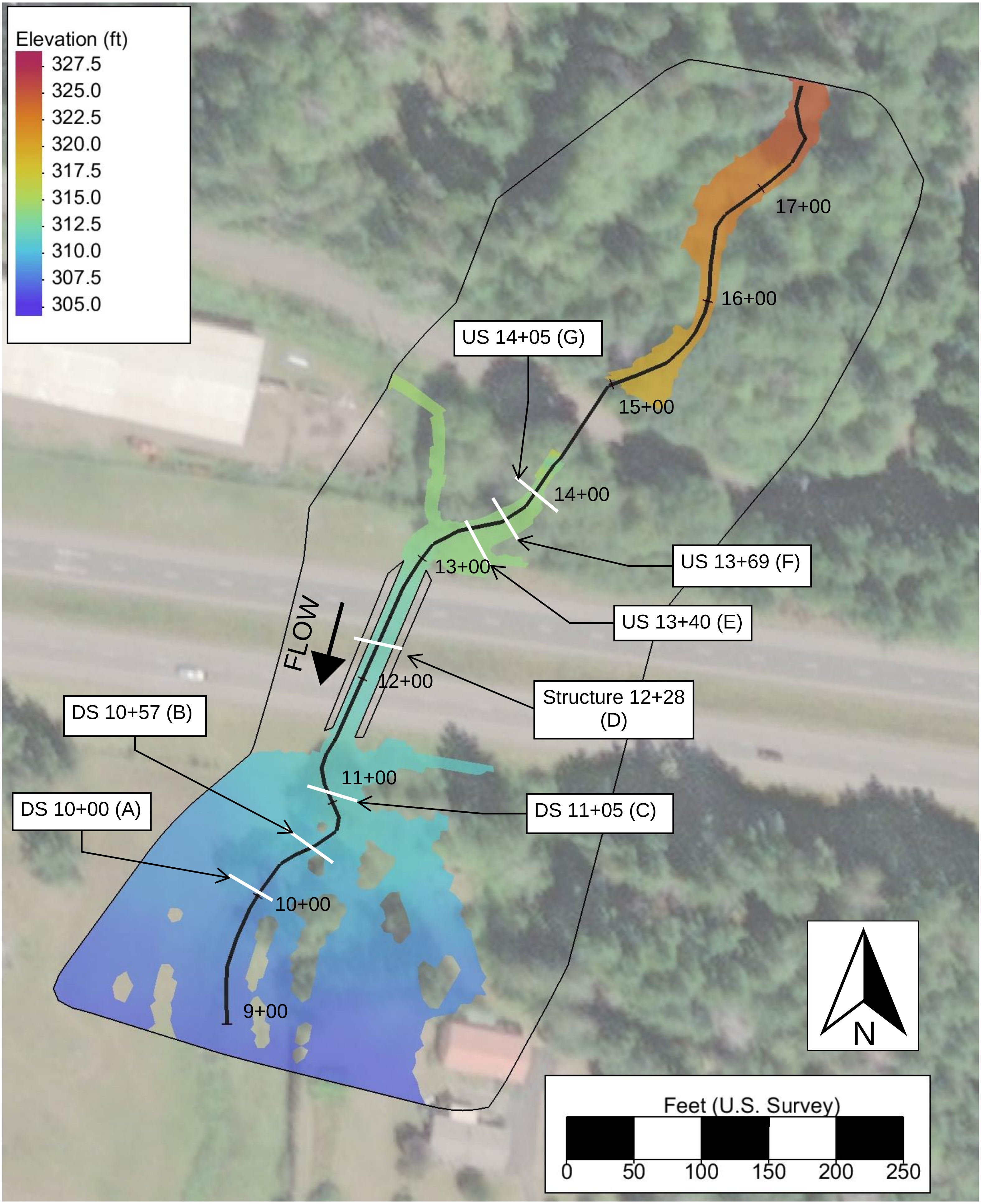


Figure H.17: Proposed conditions 100-year water surface elevation

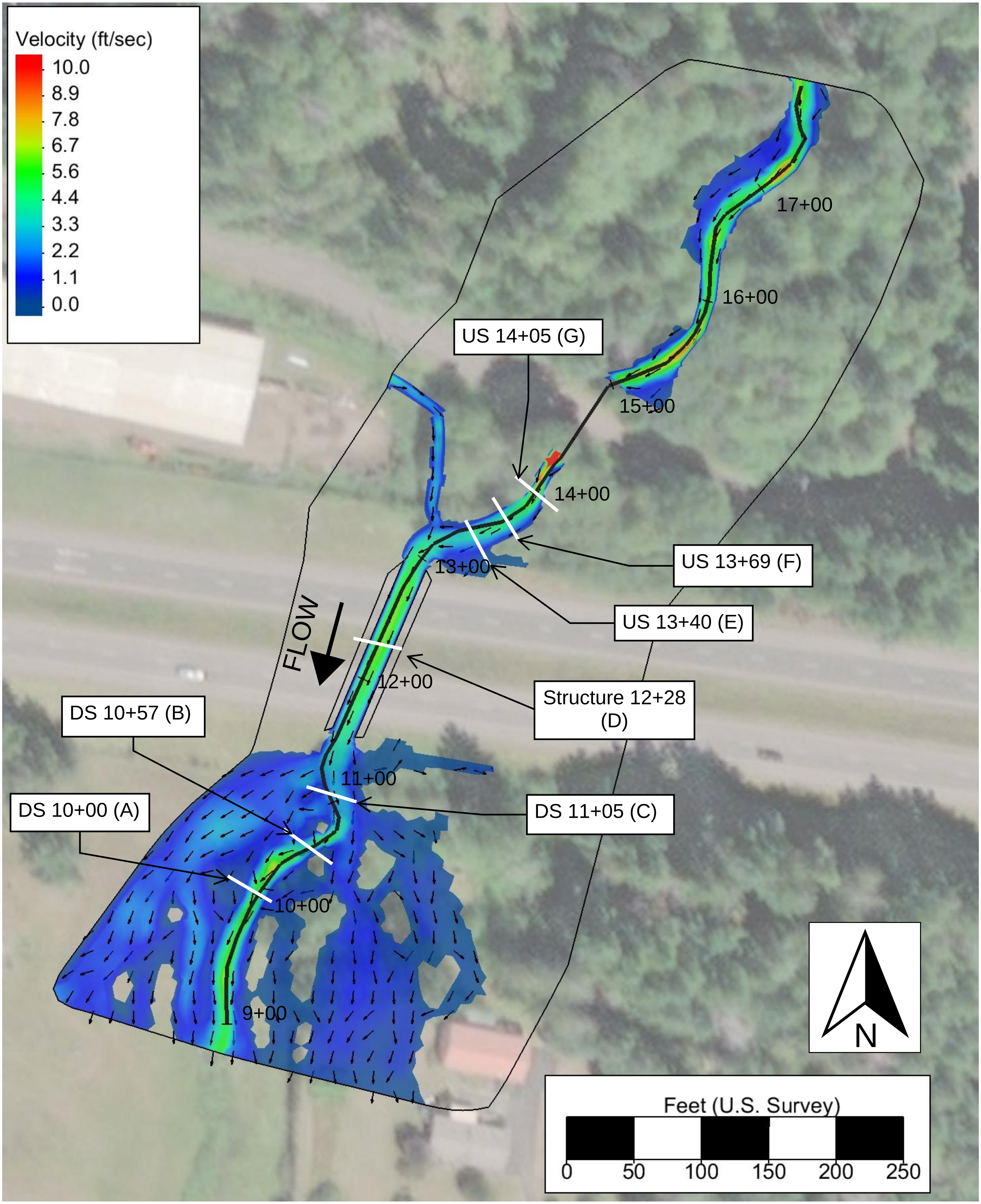


Figure H.18: Proposed conditions 100-year velocity

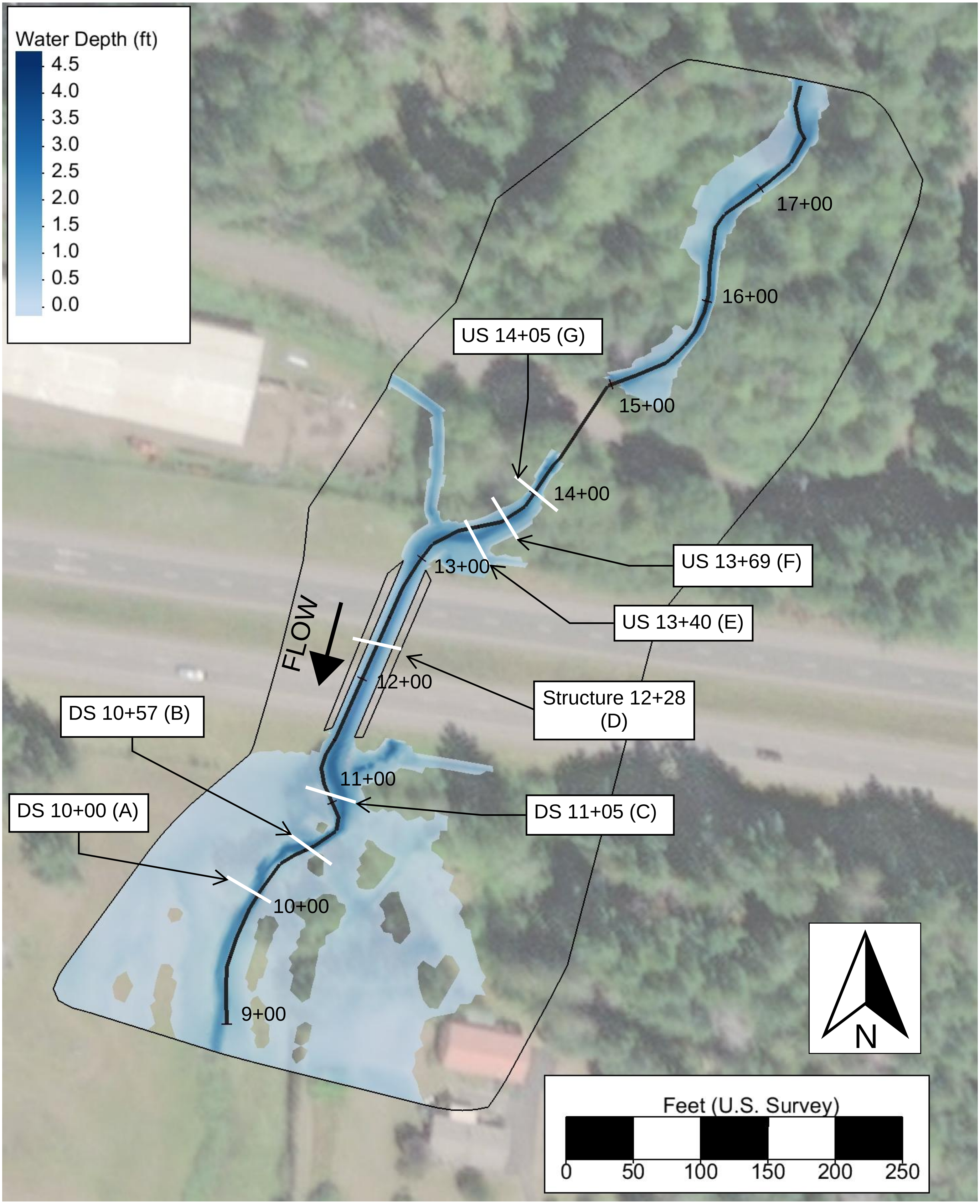


Figure H.19: Proposed conditions 100-year water depth

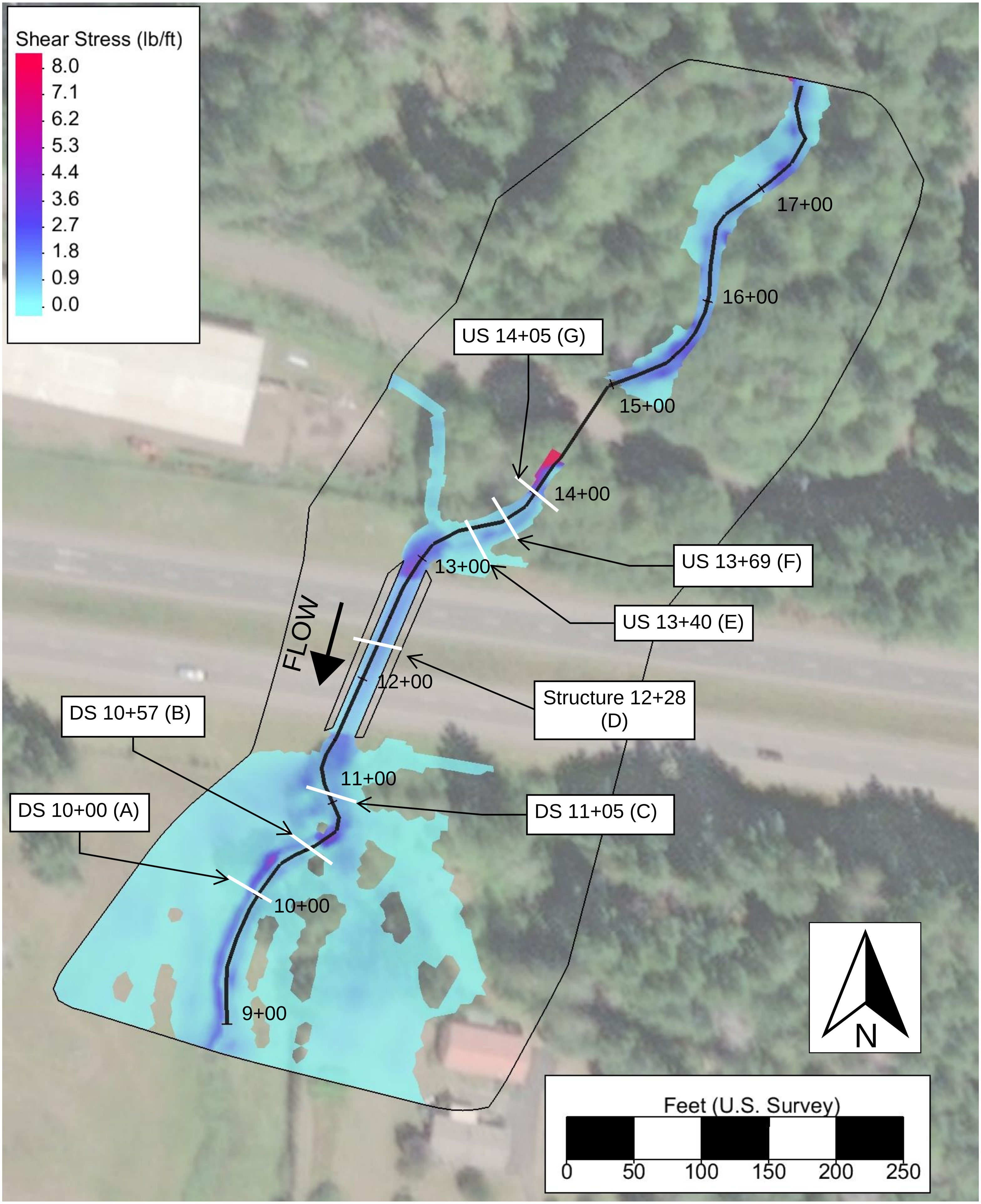


Figure H.20: Proposed conditions 100-year shear stress

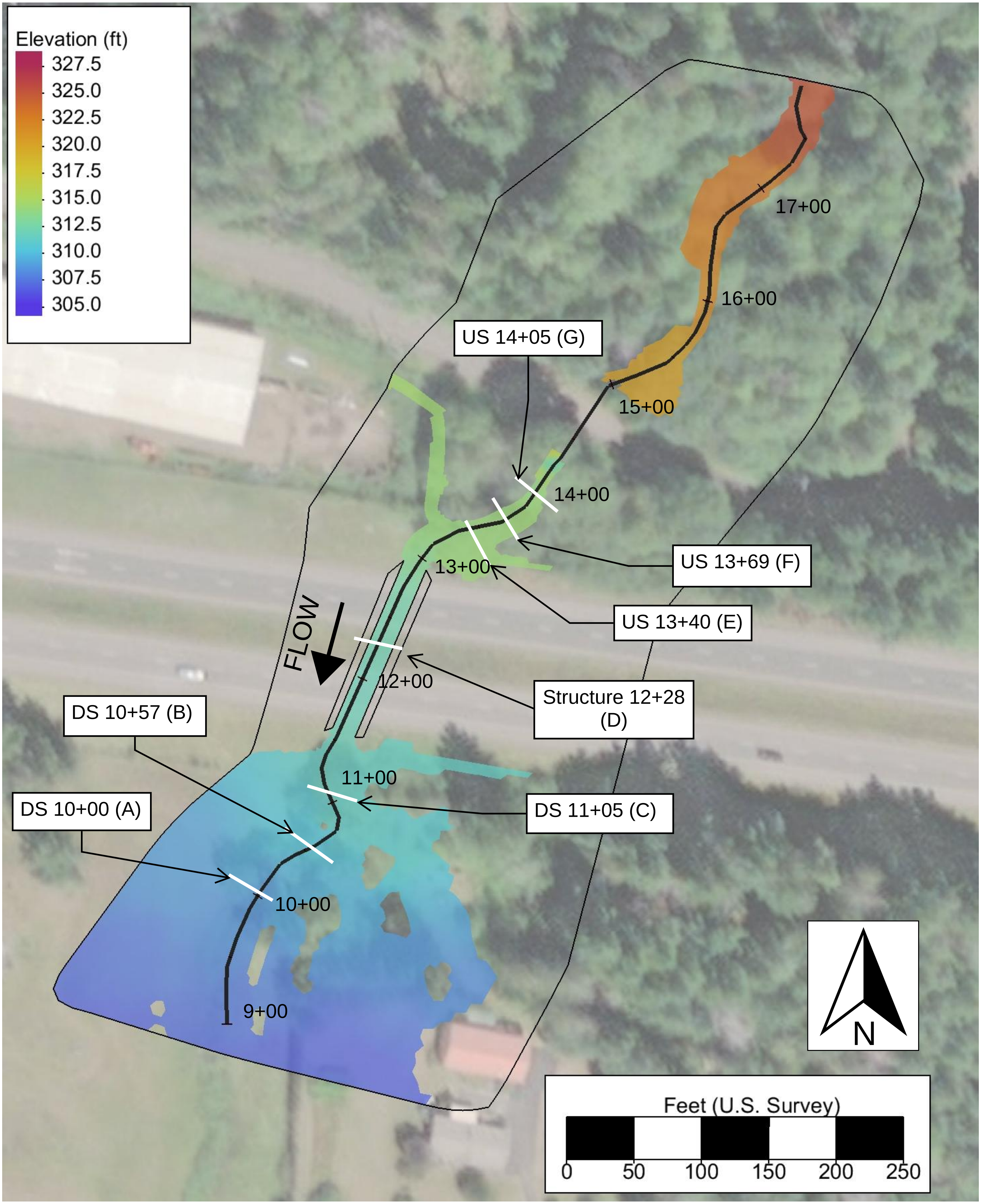


Figure H.21: Proposed conditions 500-year water surface elevation

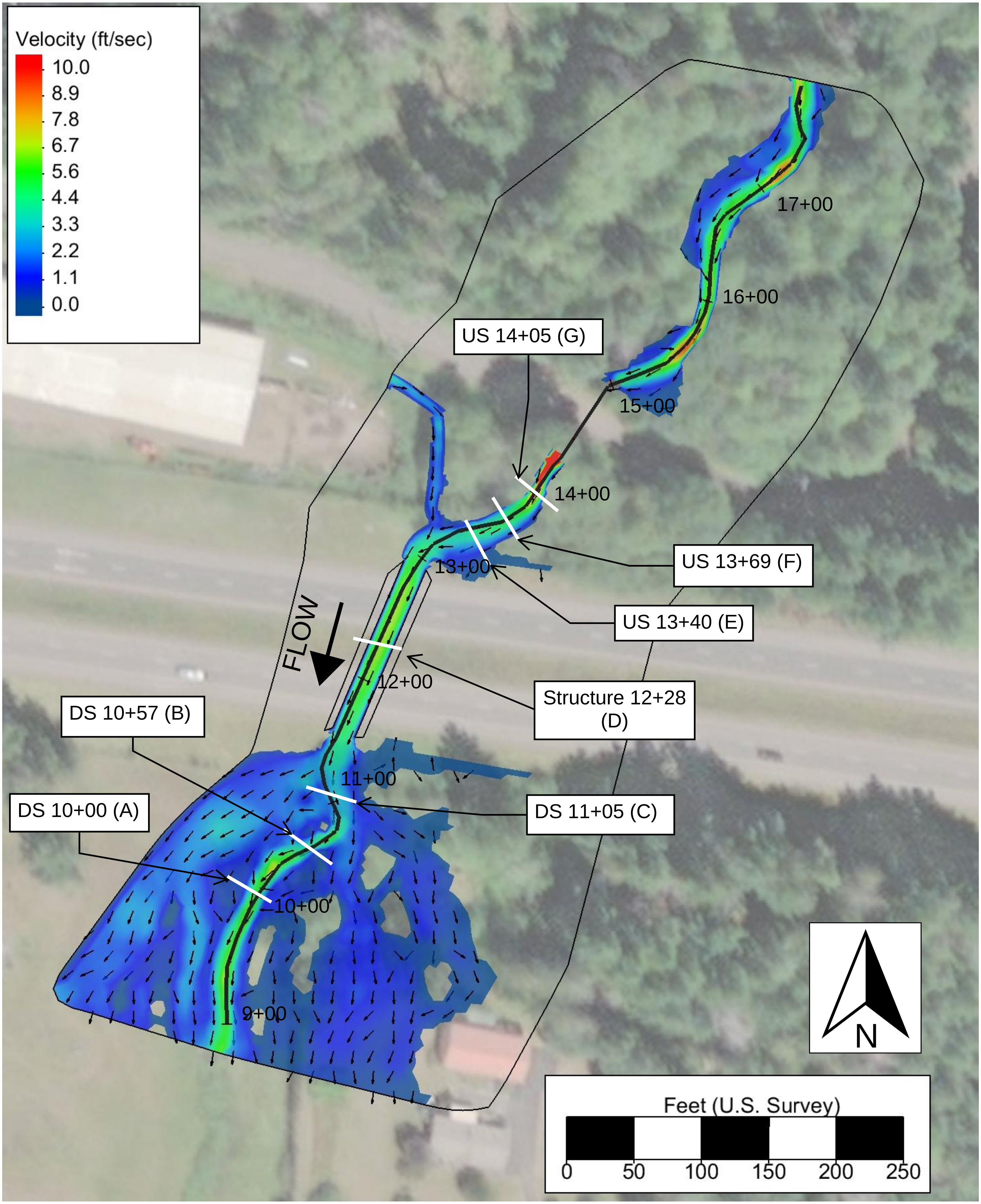


Figure H.22: Proposed conditions 500-year velocity

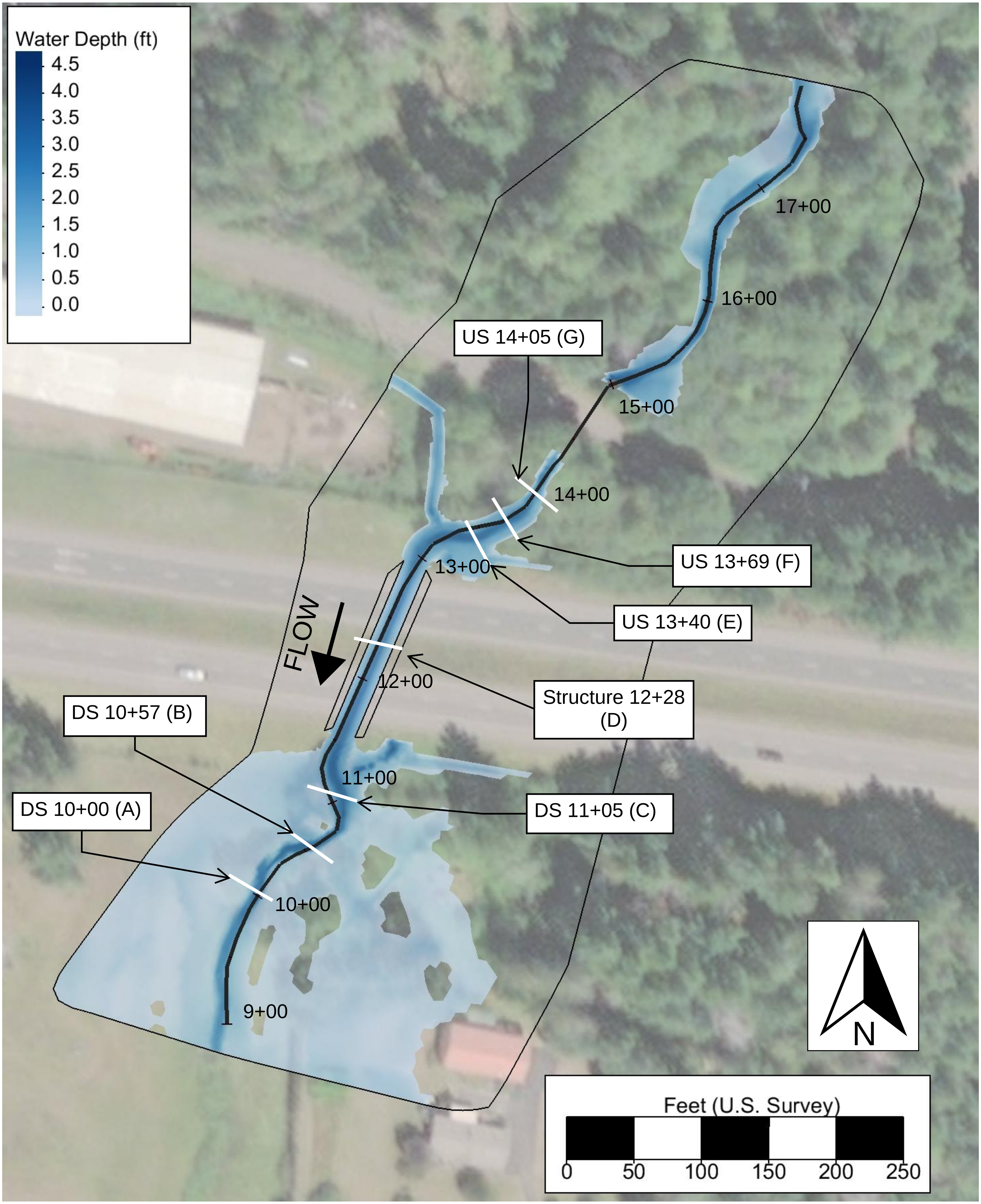


Figure H.23: Proposed conditions 500-year water depth

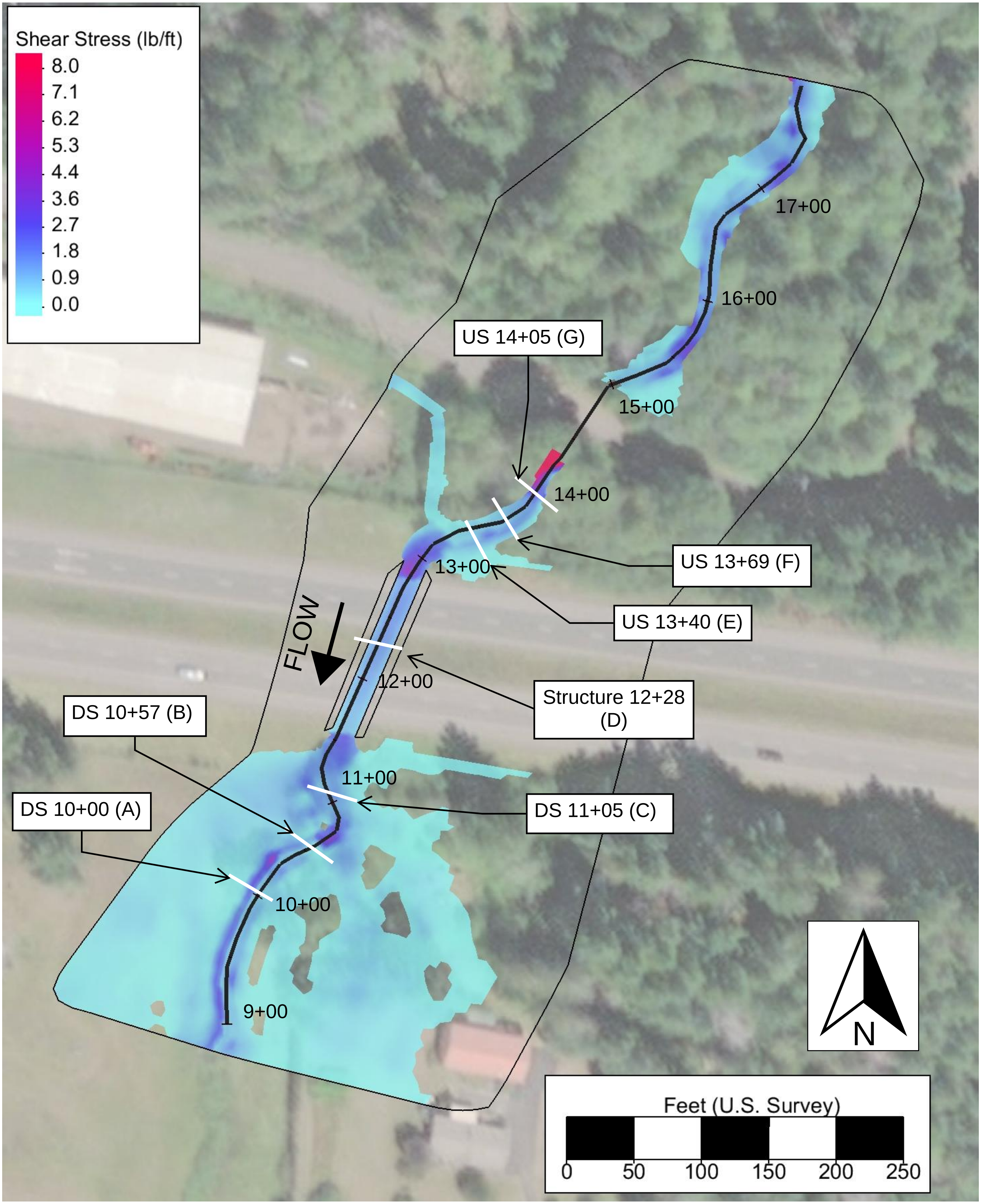


Figure H.24: Proposed conditions 500-year shear stress

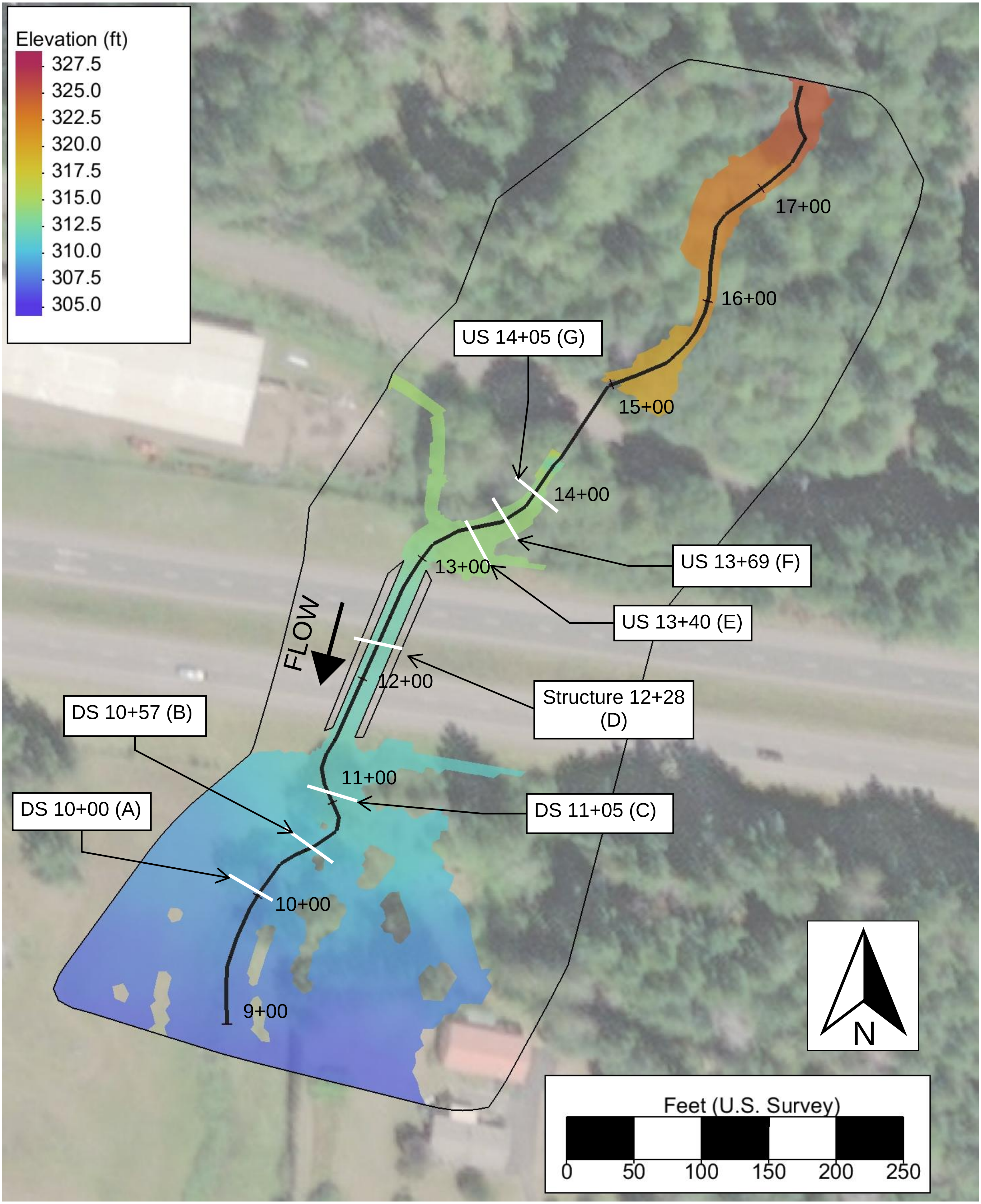


Figure H.25: Proposed conditions 2080 predicted 100-year water surface elevation

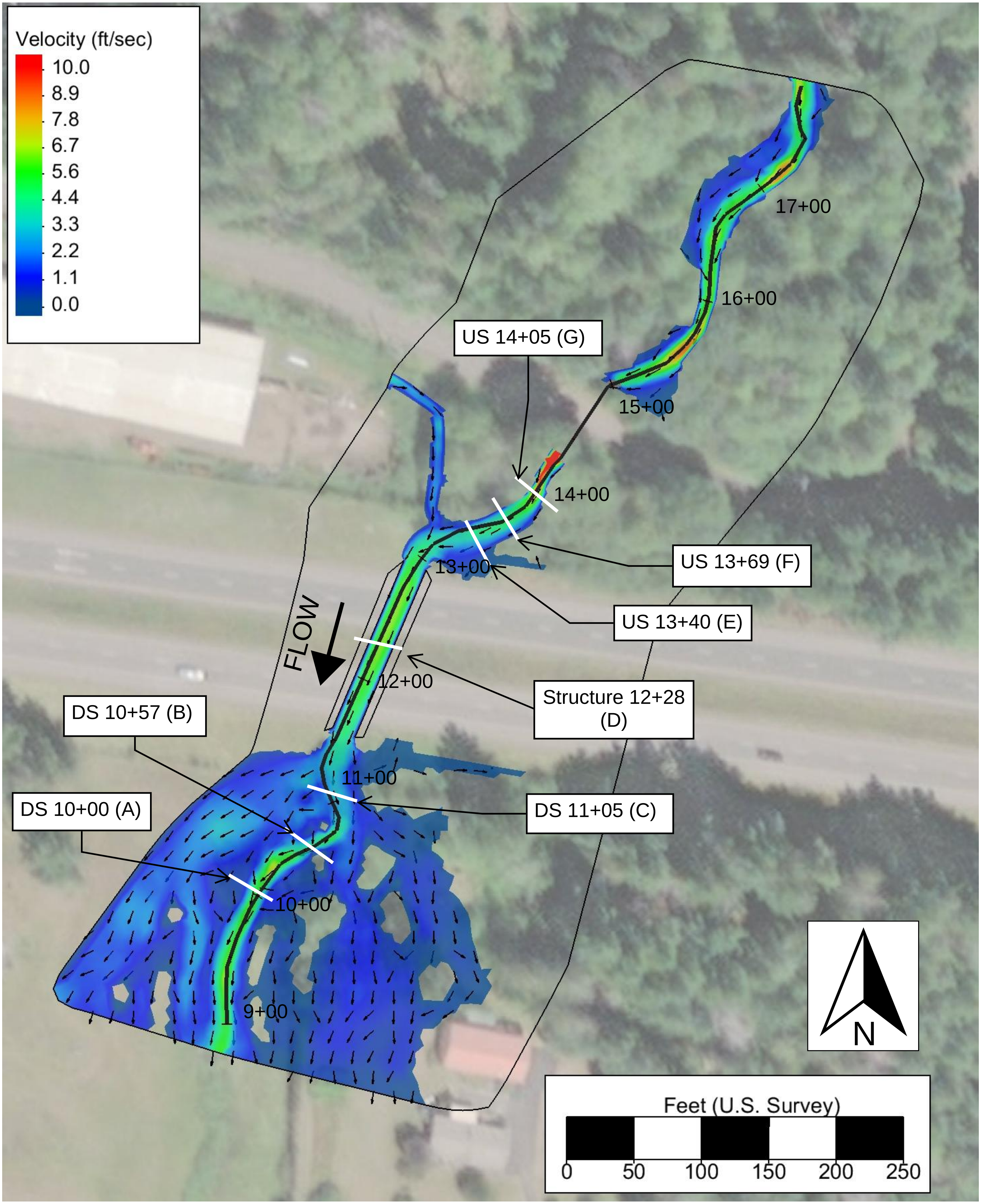


Figure H.26: Proposed conditions 2080 predicted 100-year velocity

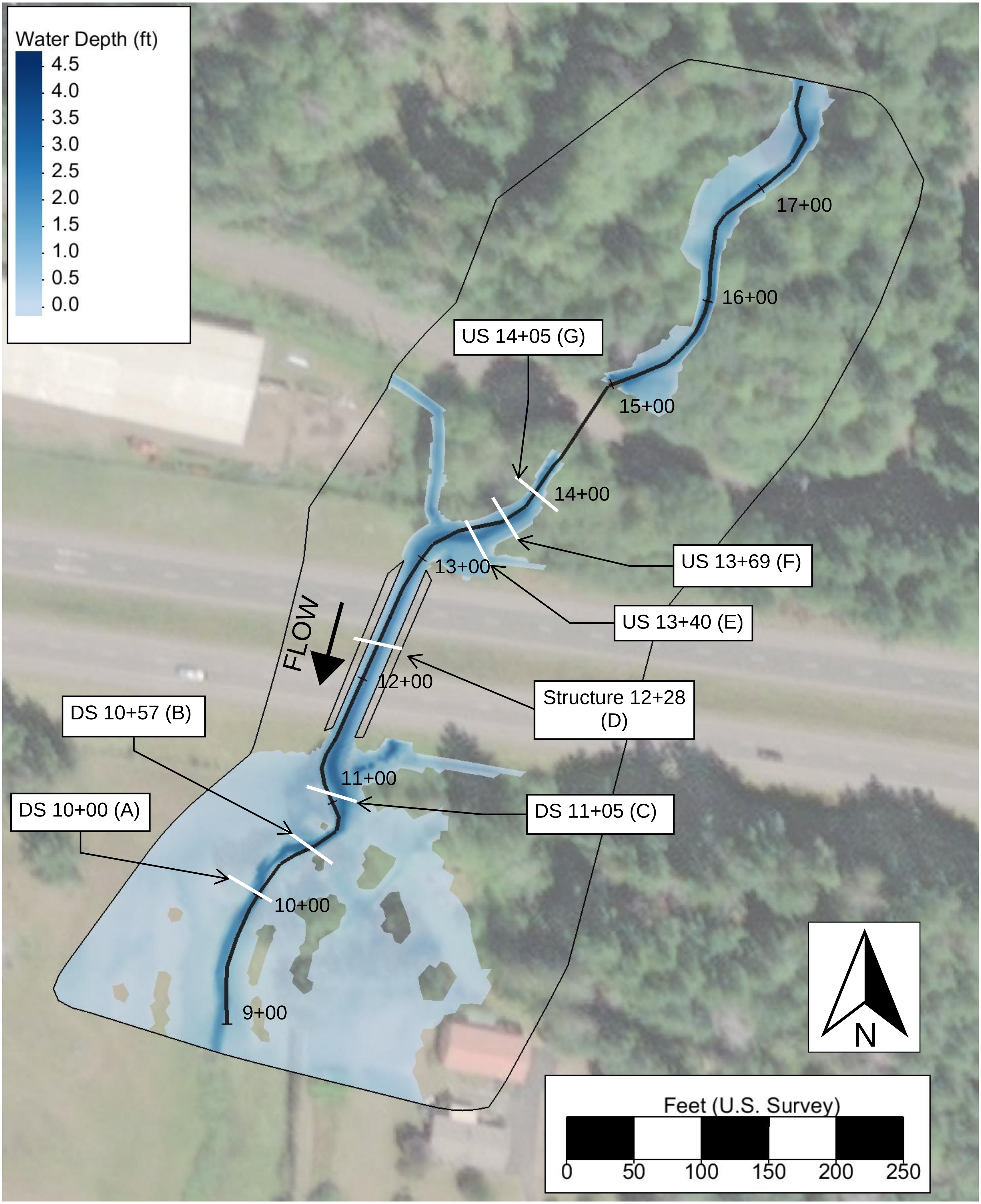


Figure H.27: Proposed conditions 2080 predicted 100-year water depth

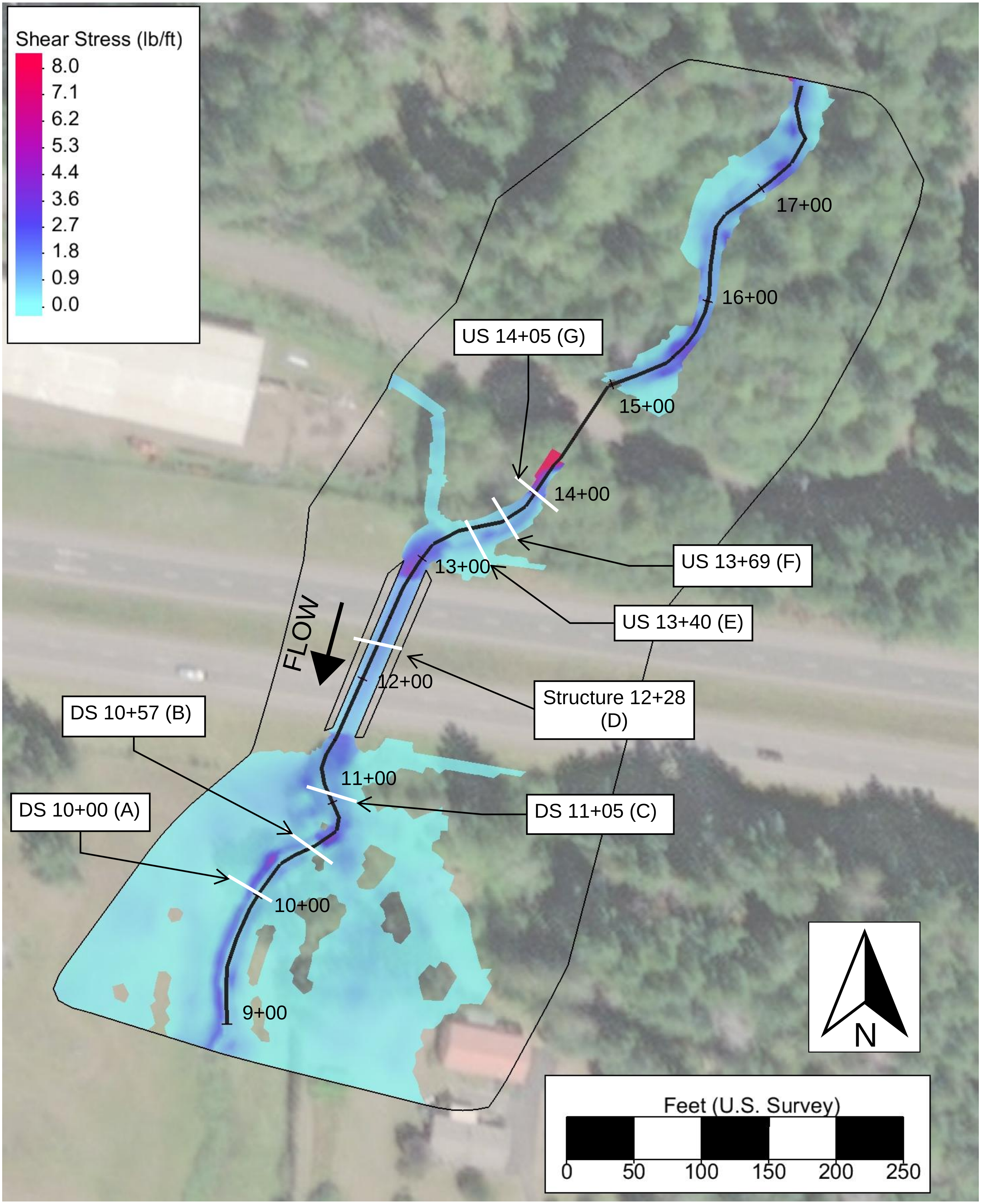


Figure H.28: Proposed conditions 2080 predicted 100-year shear stress

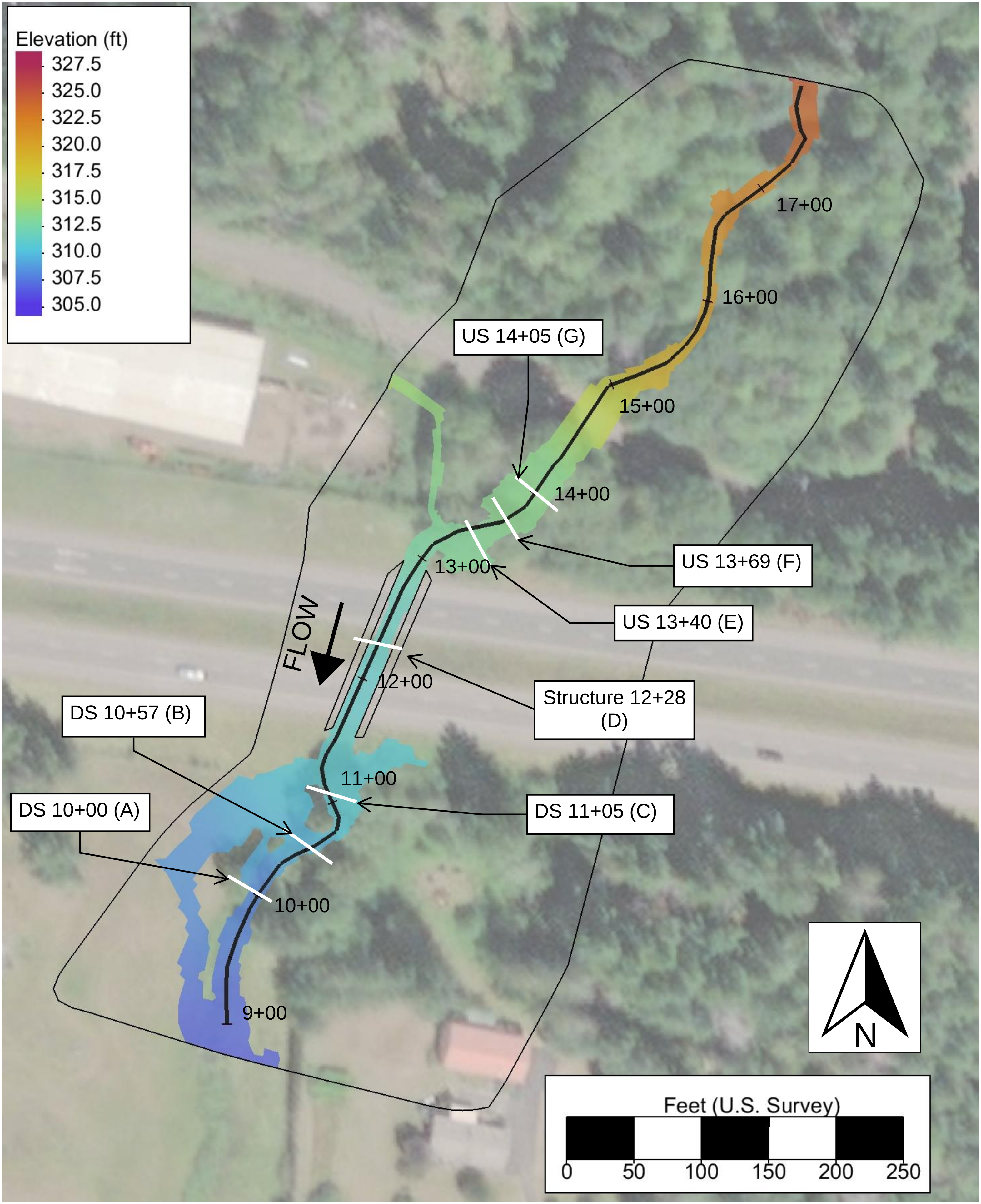


Figure H.29: Proposed conditions no McCleary Culvert 2-year water surface elevation

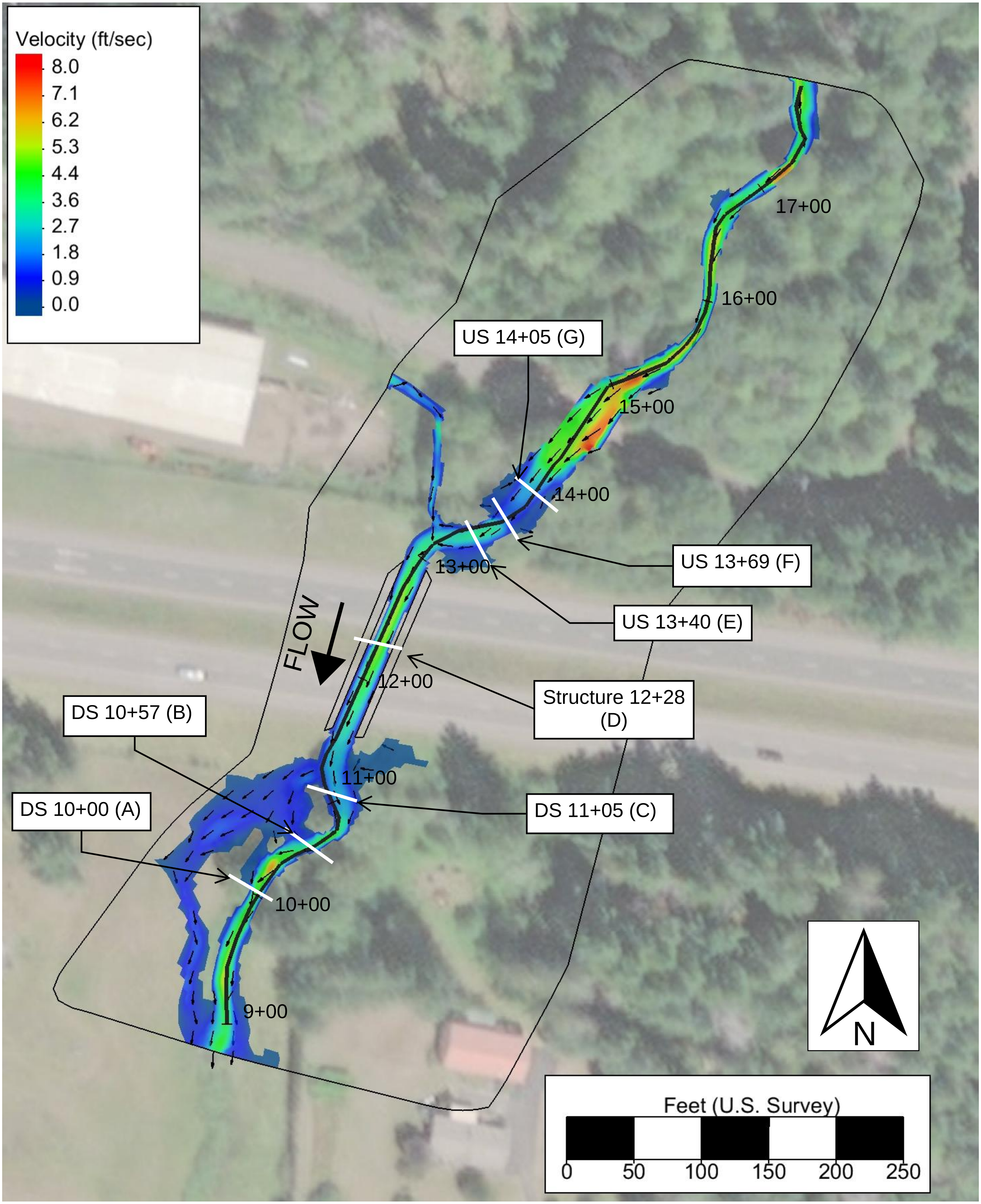


Figure H.30: Proposed conditions no McCleary Culvert 2-year velocity

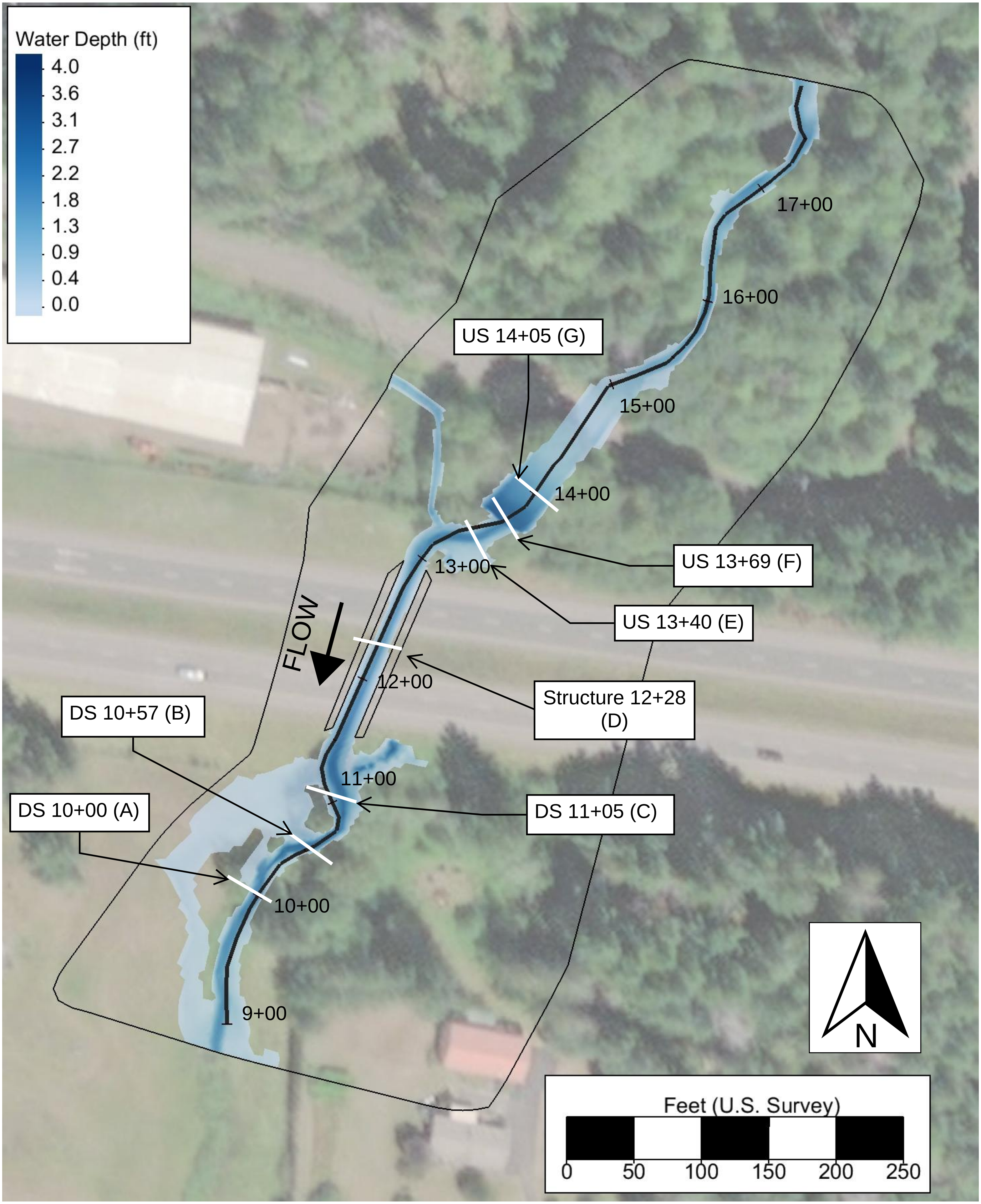


Figure H.31: Proposed conditions no McCleary Culvert 2-year water depth

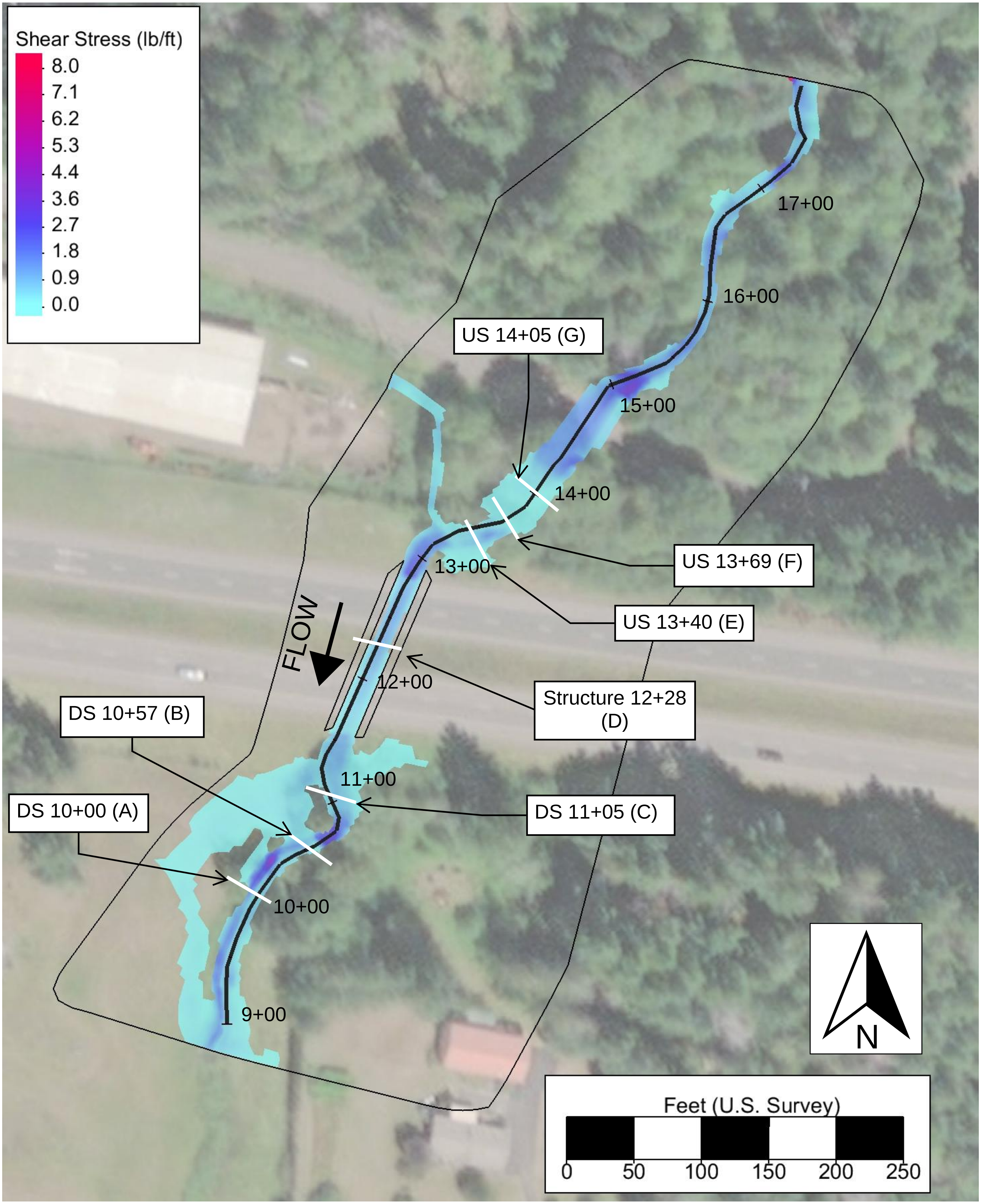


Figure H.32: Proposed conditions no McCleary Culvert 2-year shear stress

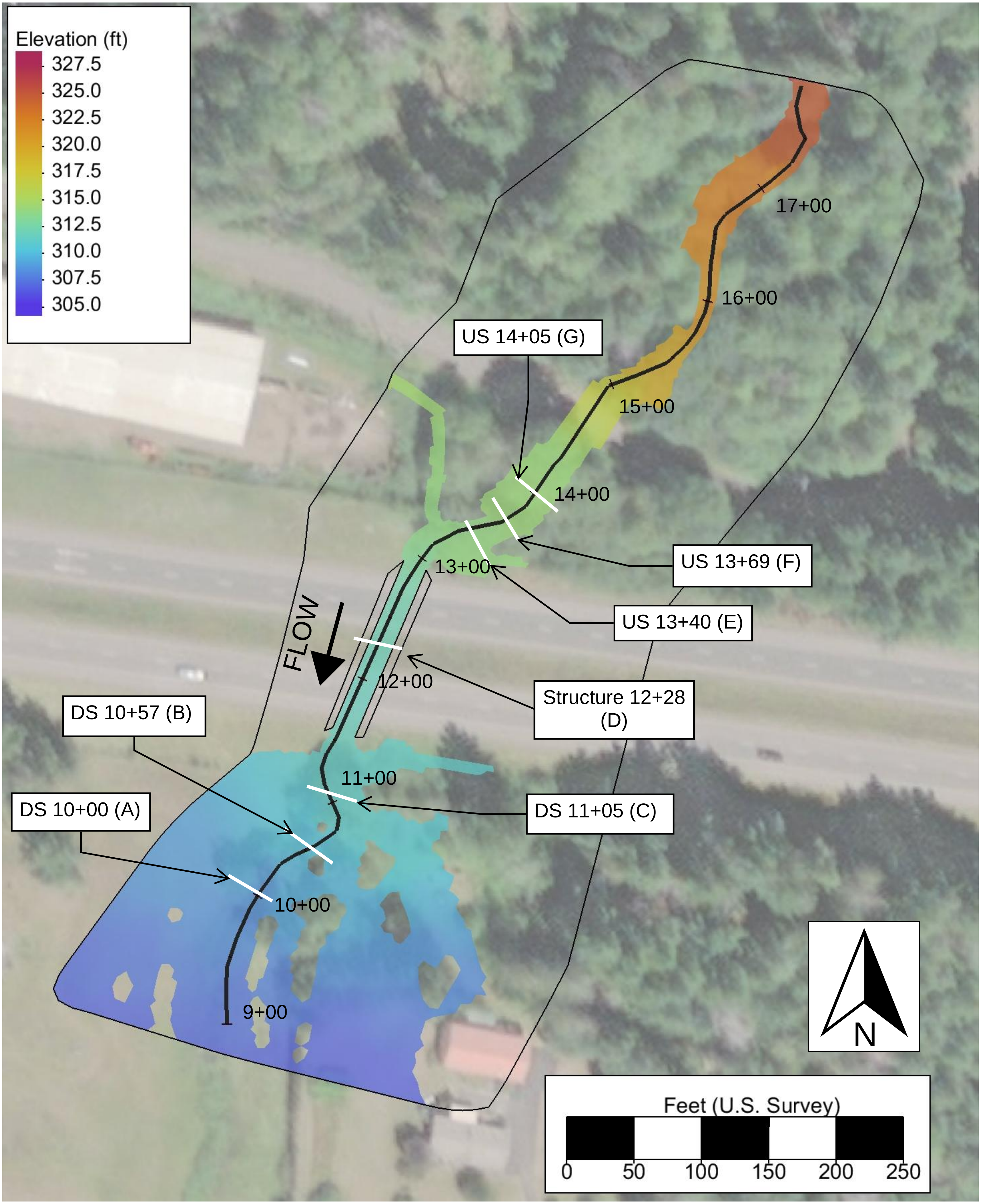


Figure H.33: Proposed conditions no McCleary Culvert 100-year water surface elevation

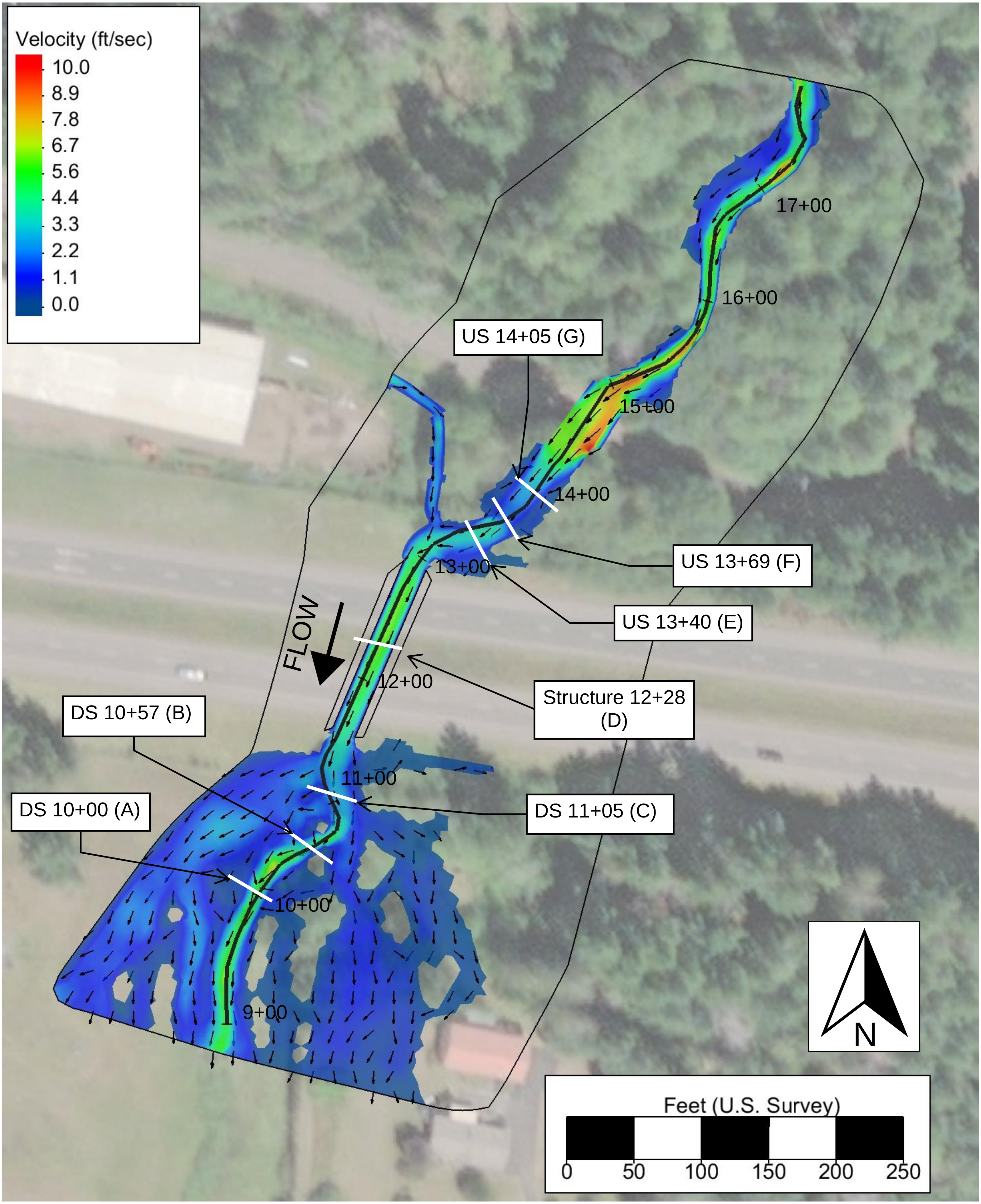


Figure H.34: Proposed conditions no McCleary Culvert 100-year velocity

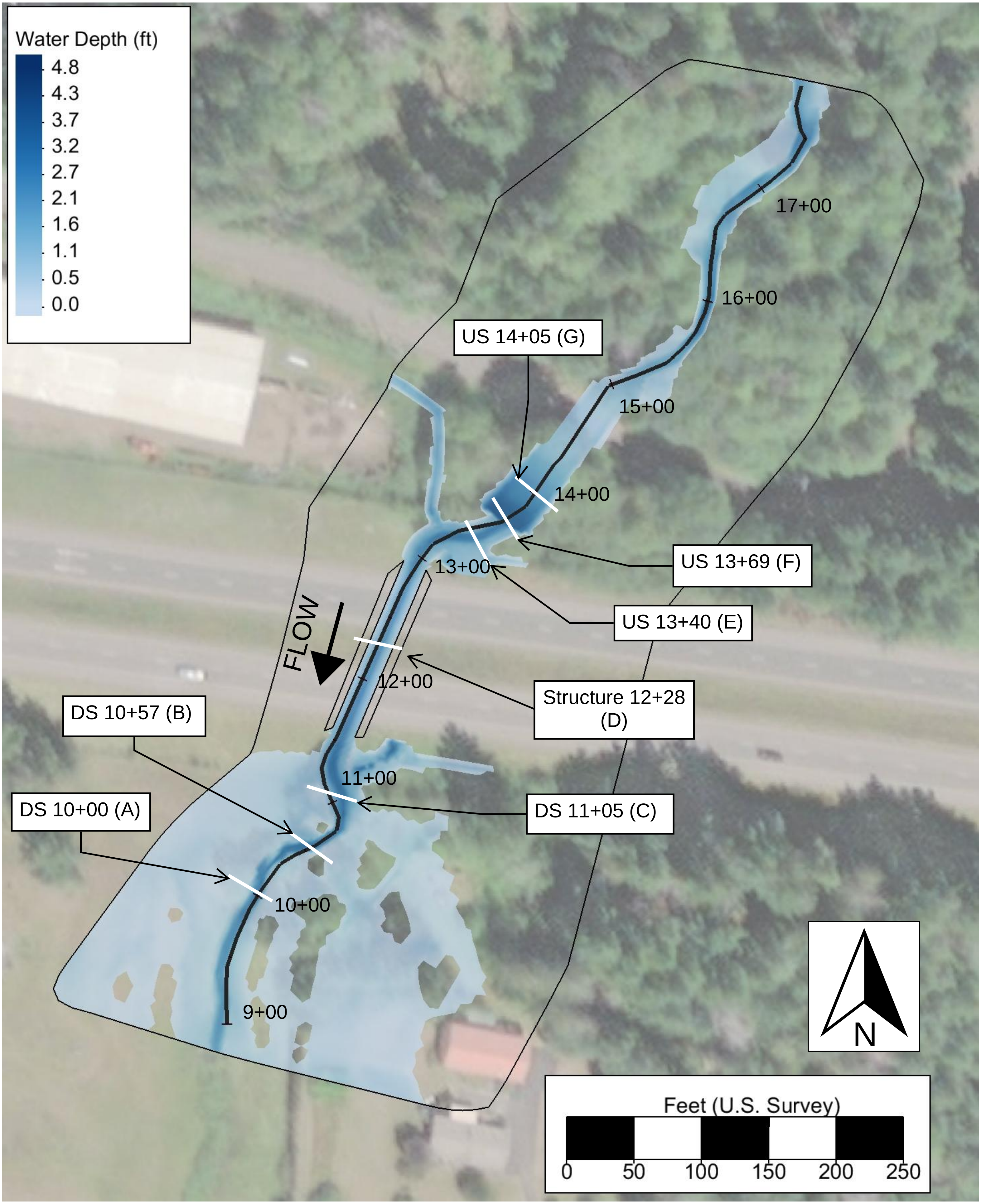


Figure H.35: Proposed conditions no McCleary Culvert 100-year water depth

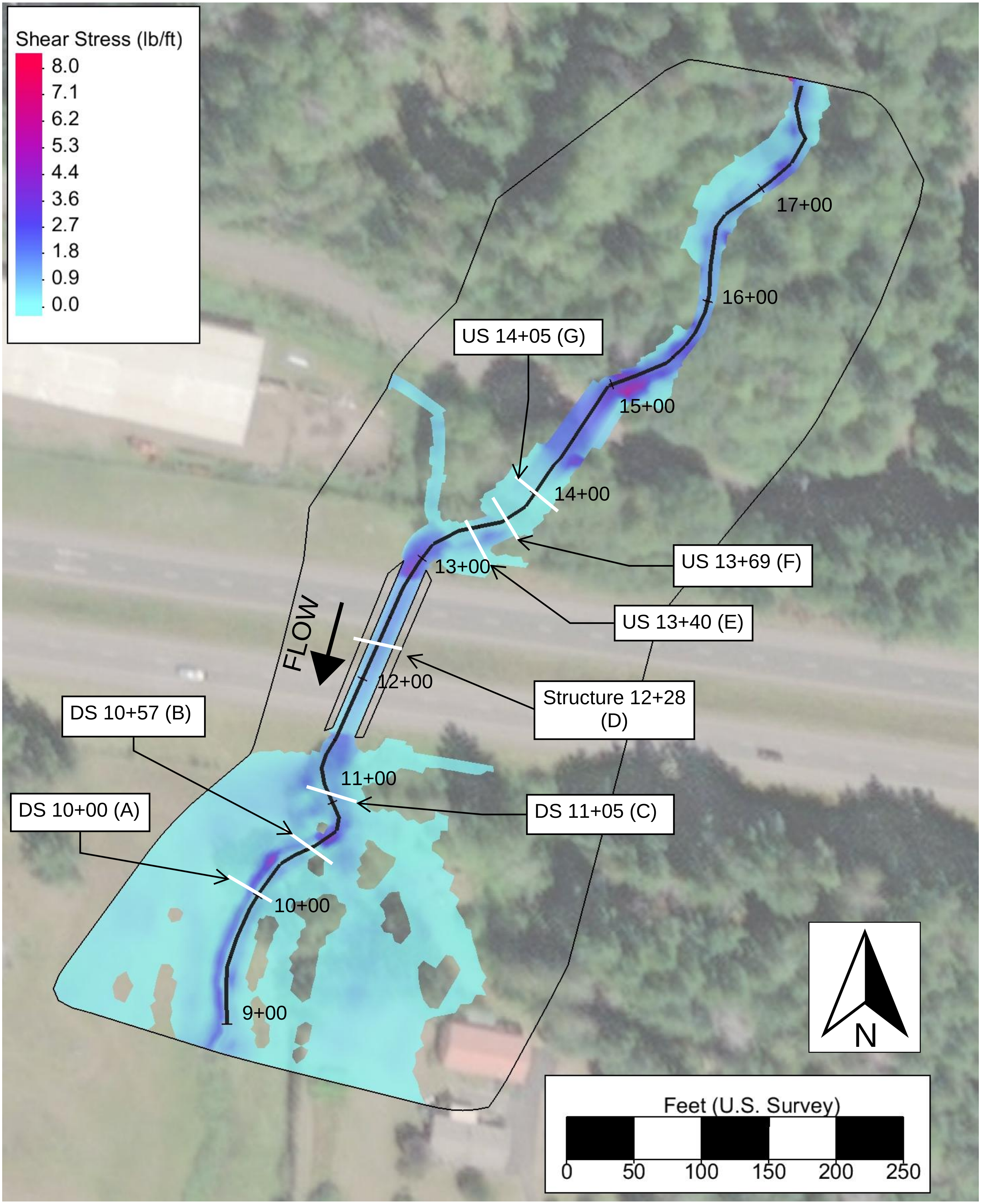


Figure H.36: Proposed conditions no McCleary Culvert 100-year shear stress

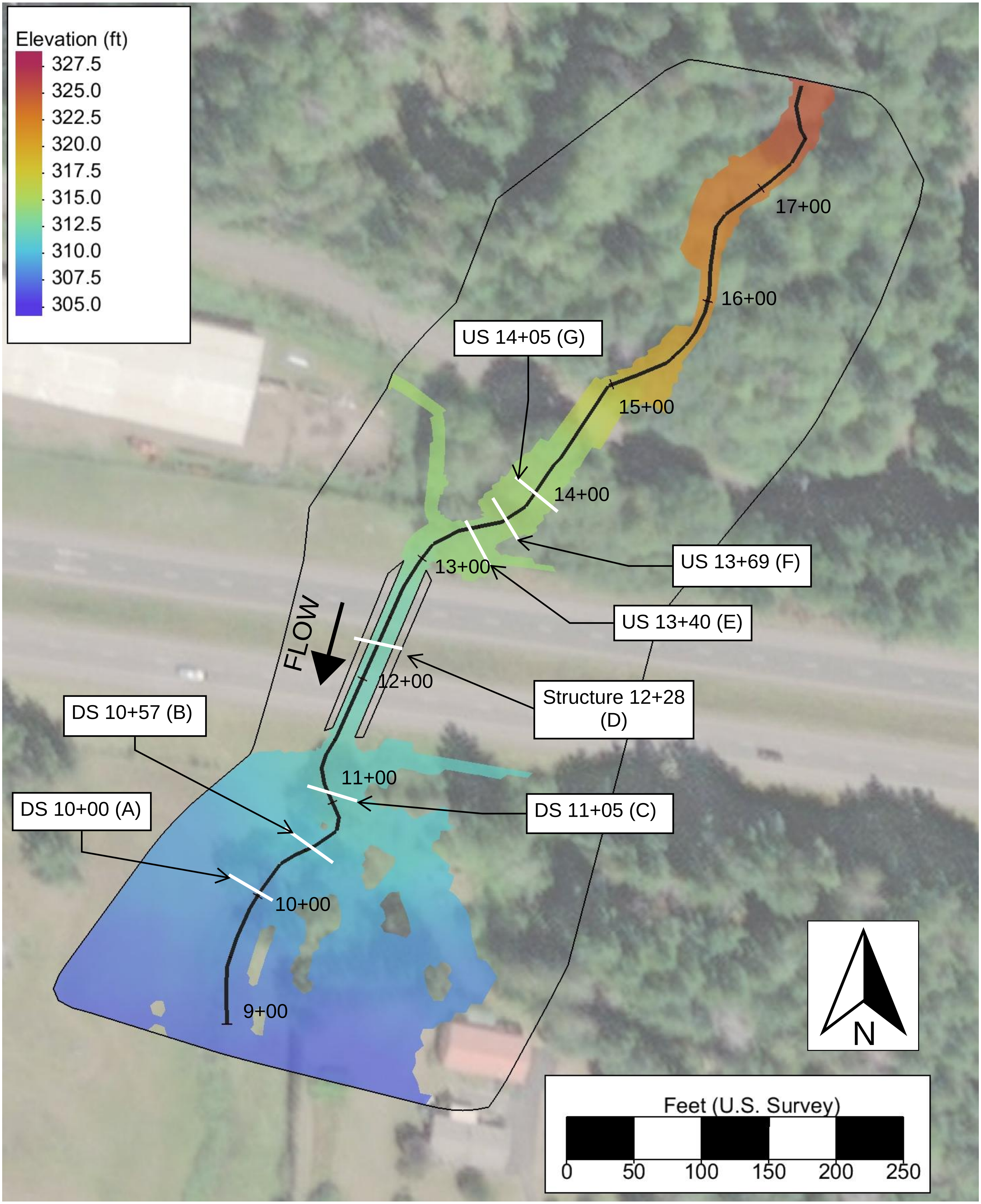


Figure H.37: Proposed conditions no McCleary Culvert 500-year water surface elevation

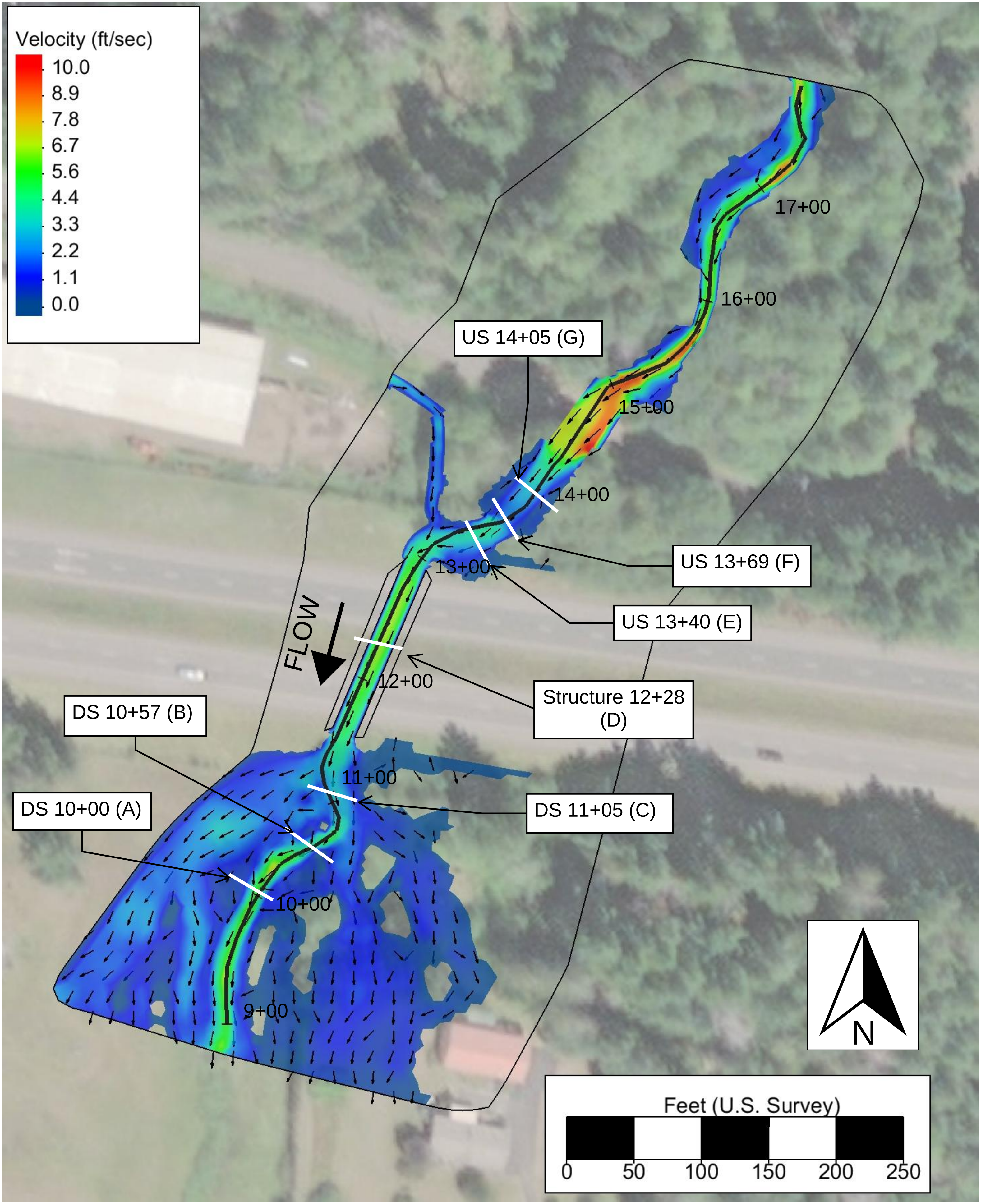


Figure H.38: Proposed conditions no McCleary Culvert 500-year velocity

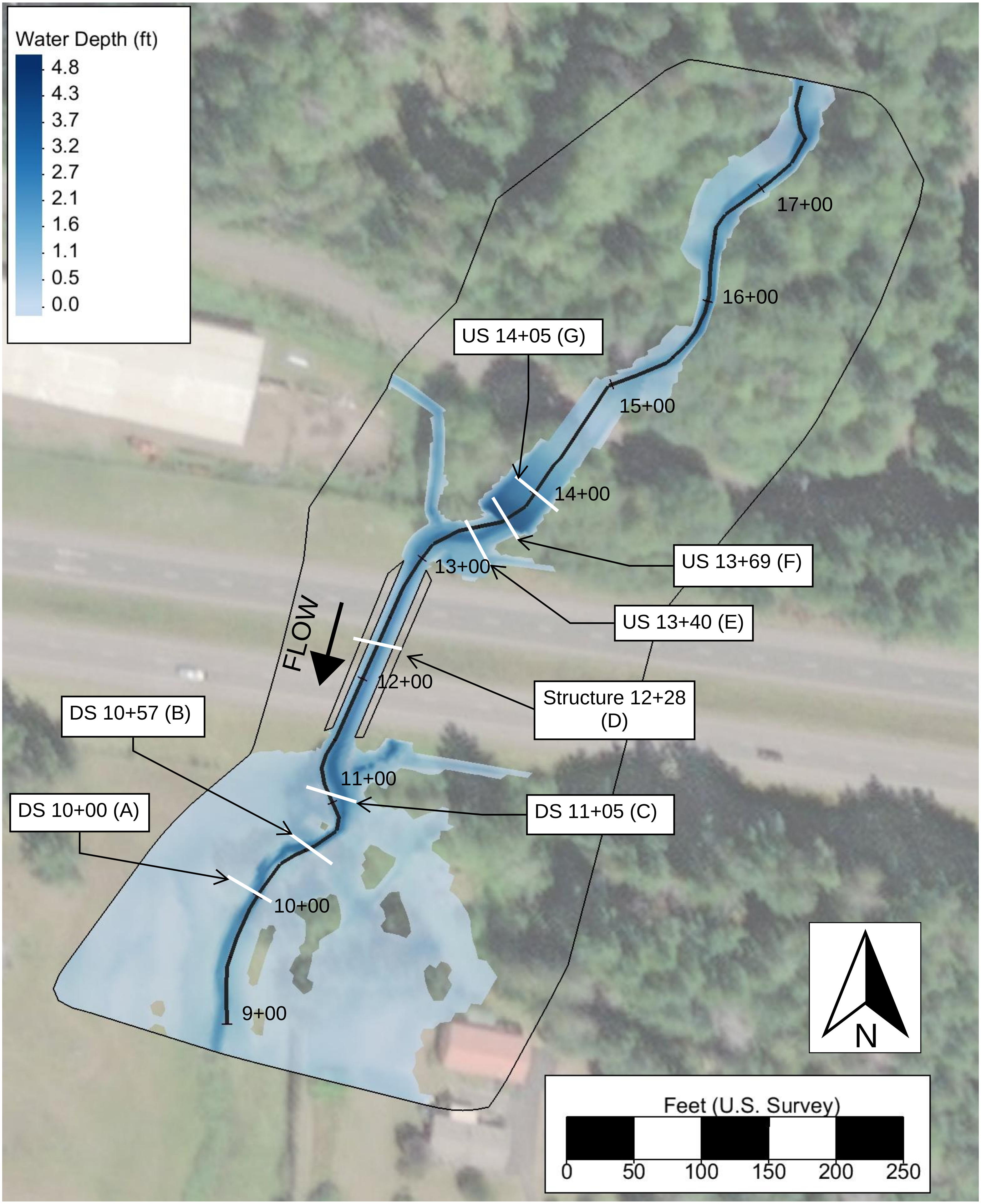


Figure H.39: Proposed conditions no McCleary Culvert 500-year water depth

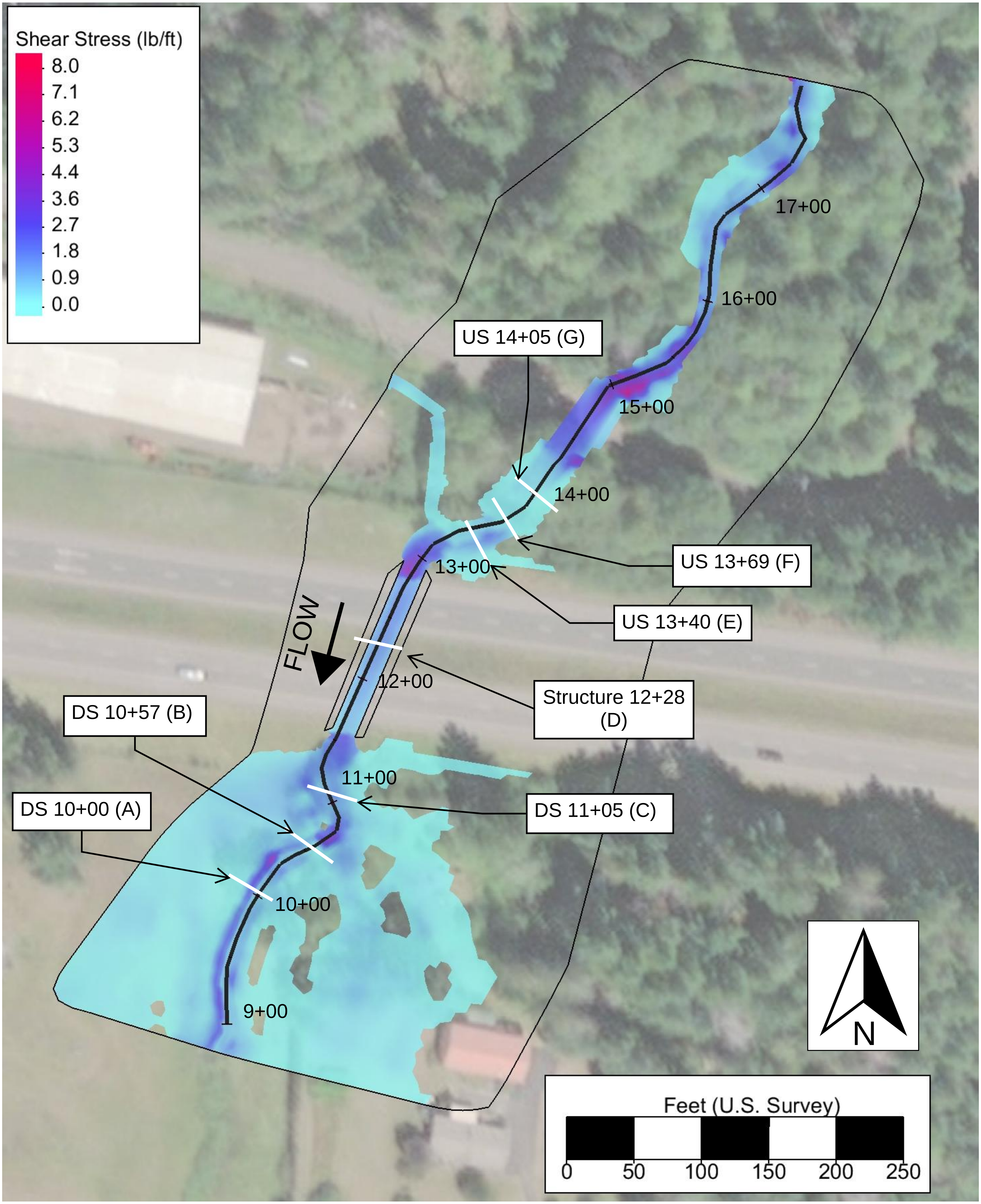


Figure H.40: Proposed conditions no McCleary Culvert 500-year shear stress

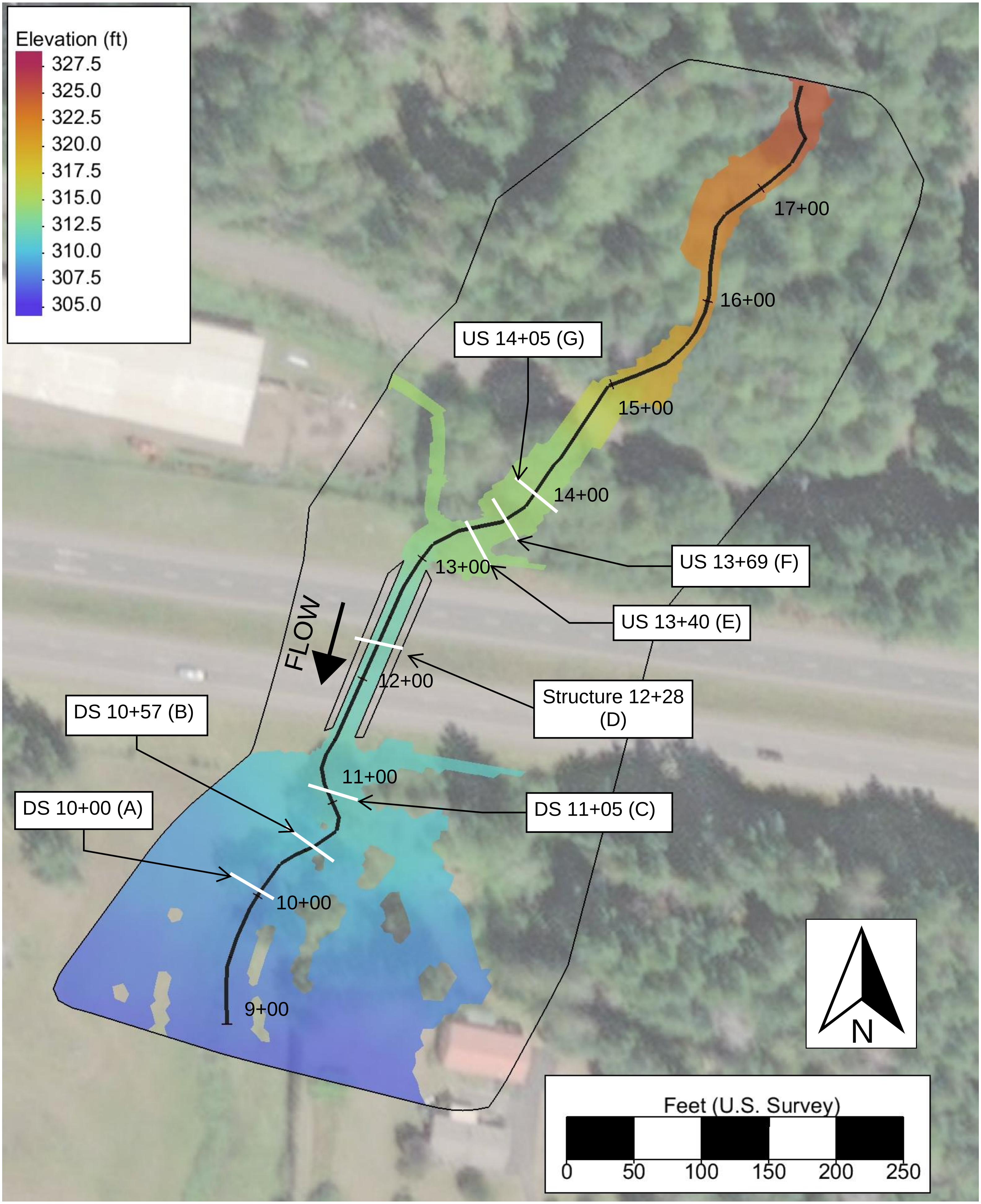


Figure H.41: Proposed conditions no McCleary Culvert 2080 predicted 100-year water surface elevation

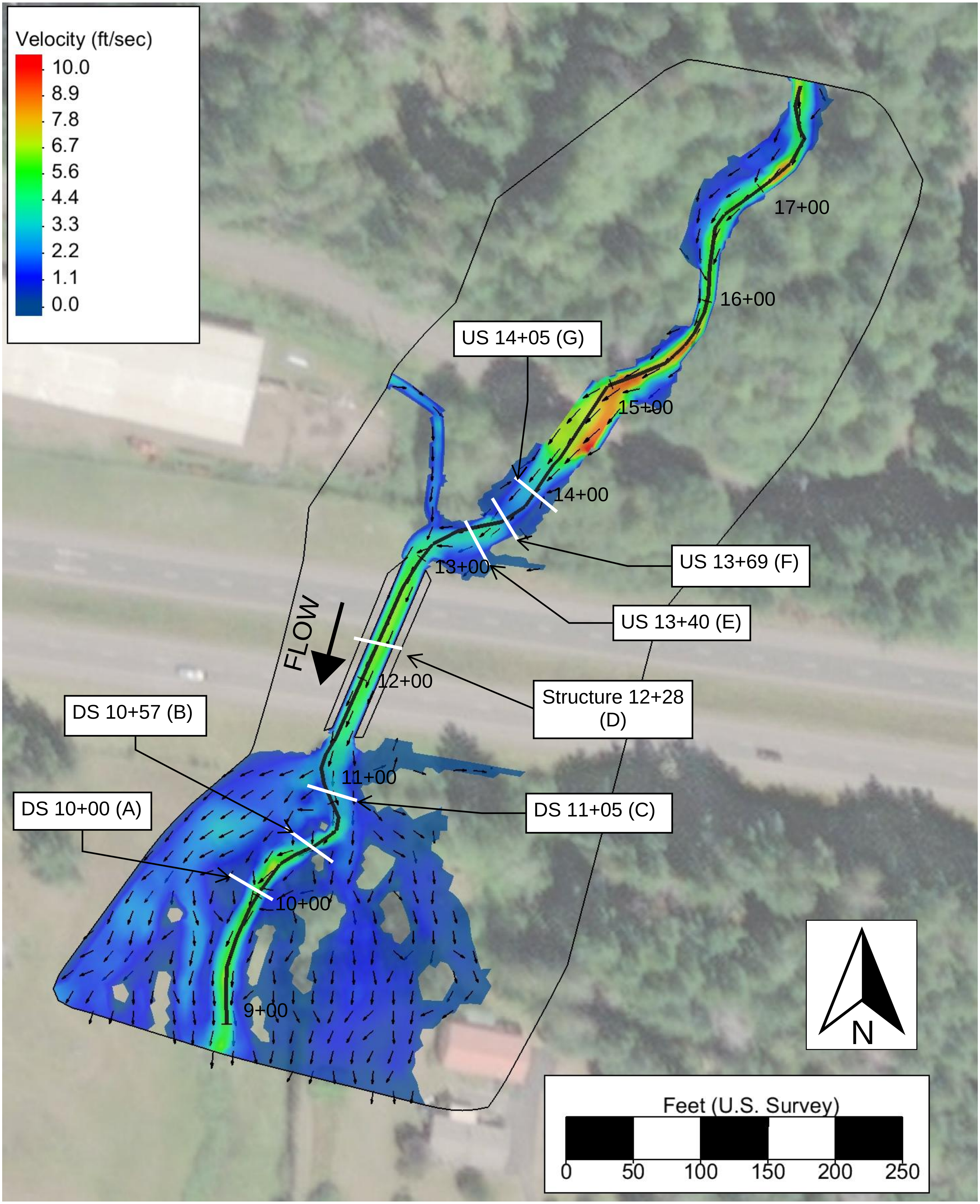


Figure H.42: Proposed conditions no McCleary Culvert 2080 predicted 100-year velocity

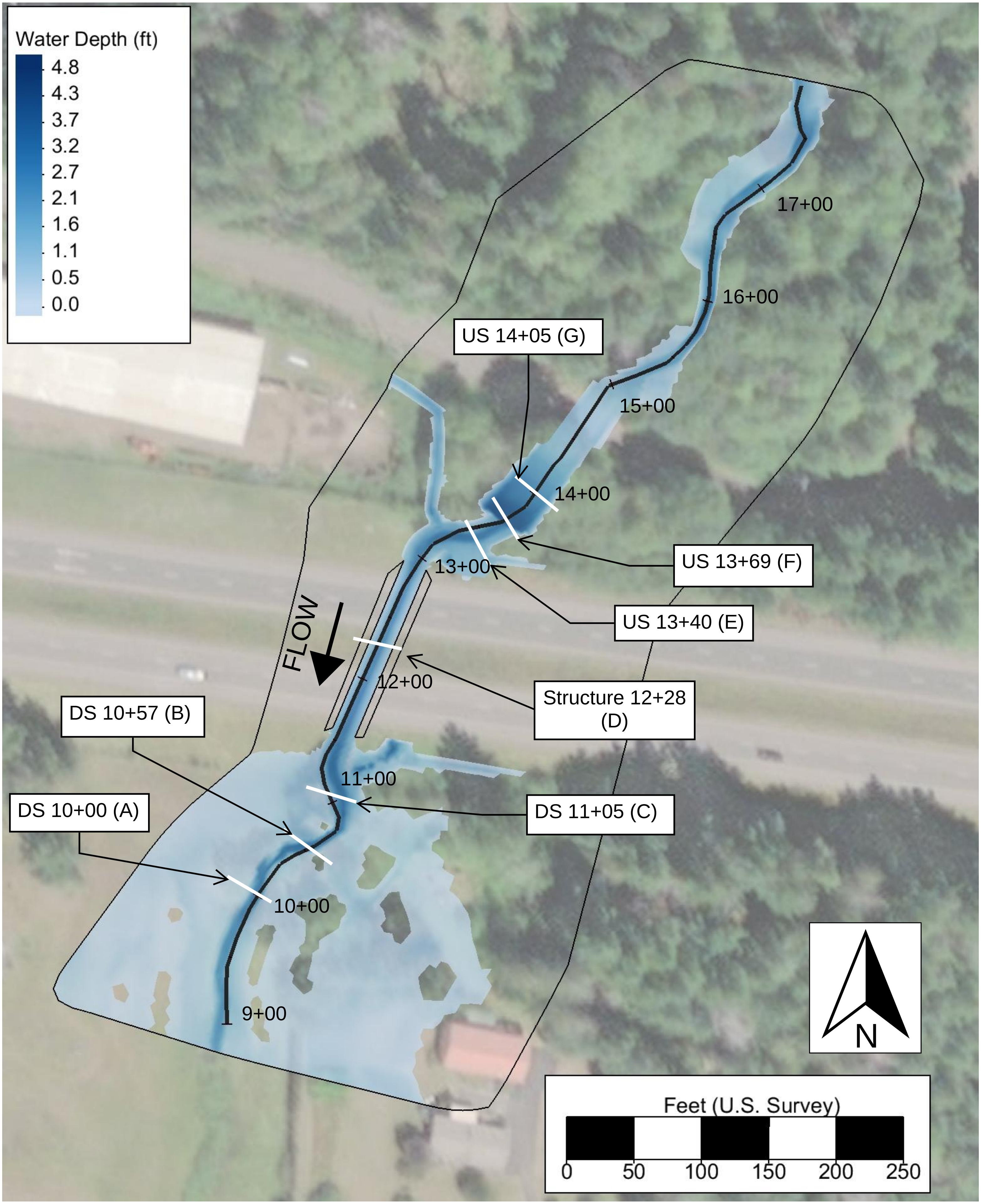


Figure H.43: Proposed conditions no McCleary Culvert 2080 predicted 100-year water depth

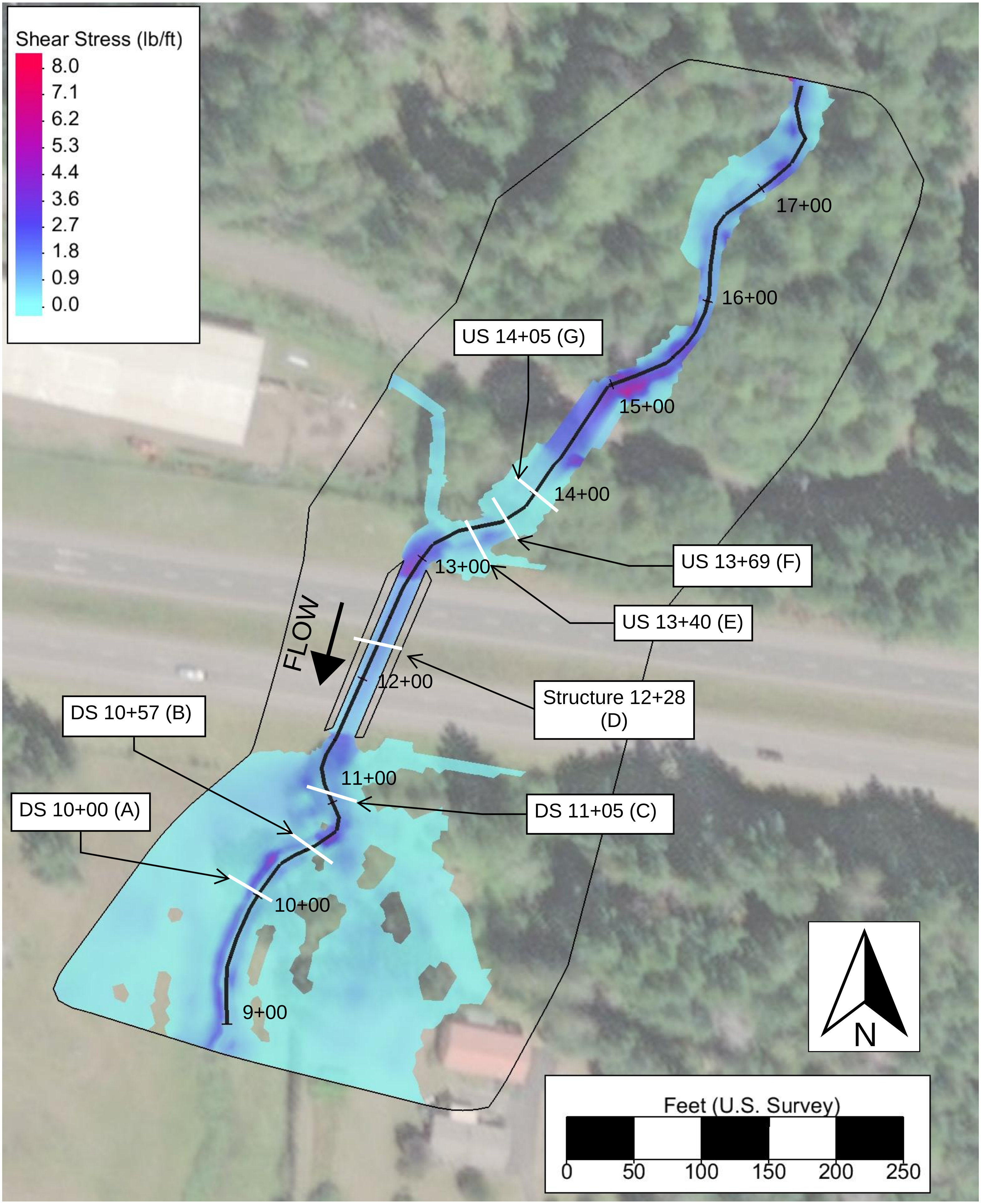


Figure H.44: Proposed conditions no McCleary Culvert 2080 predicted 100-year shear stress

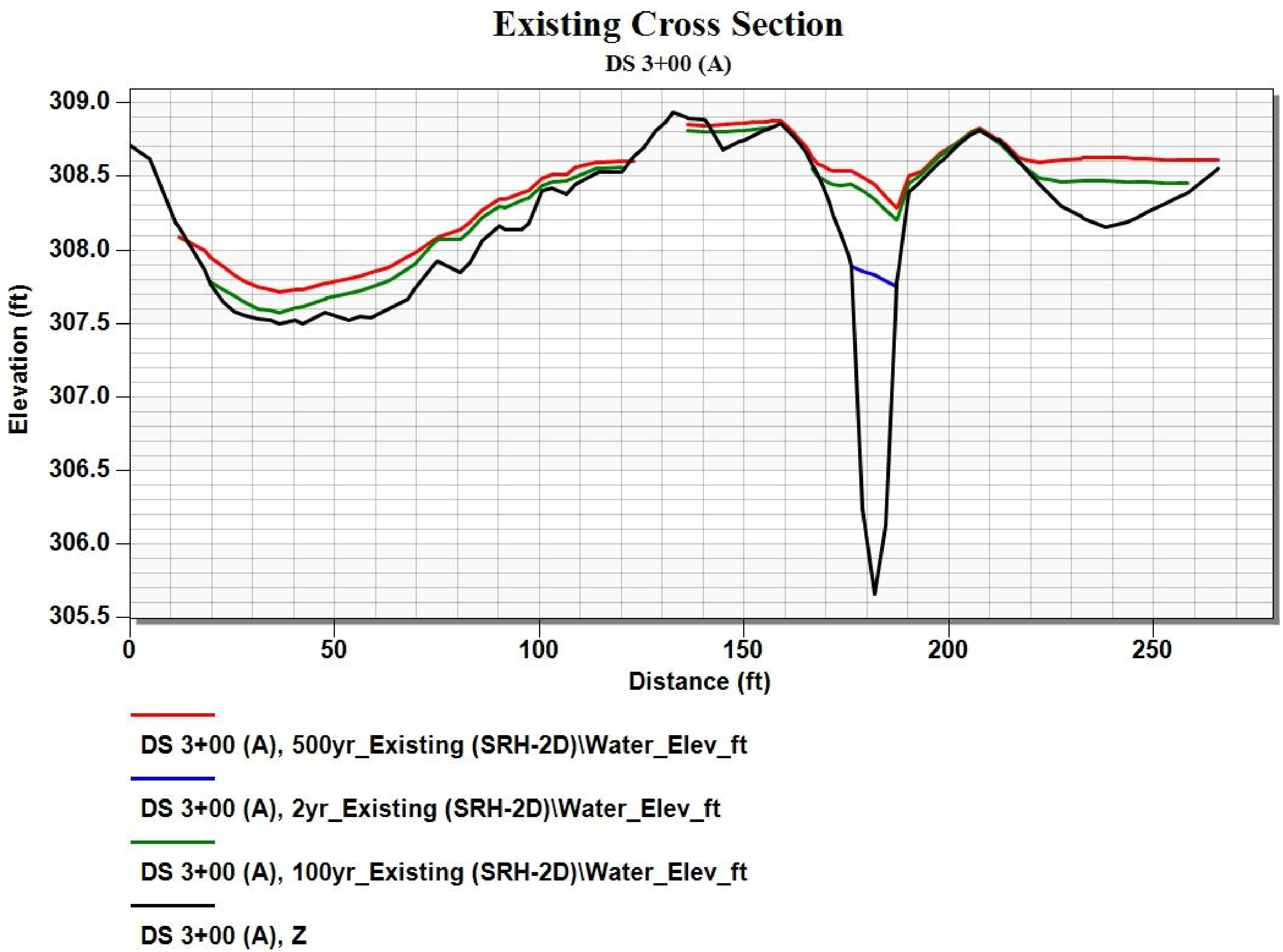


Figure H.45: Existing conditions cross section at downstream station 3+00 (A)

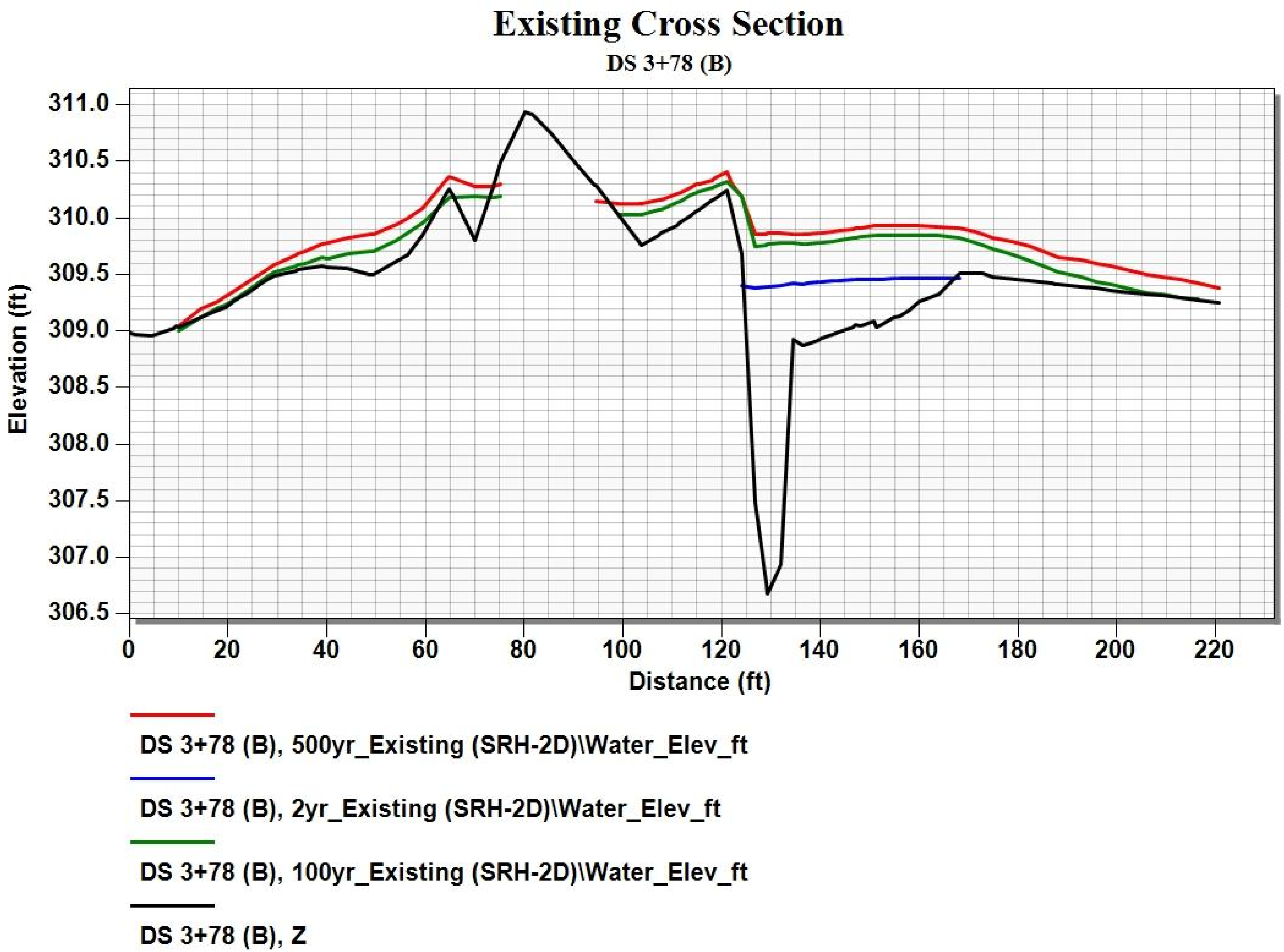


Figure H.46: Existing conditions cross section at downstream station 3+78 (B)

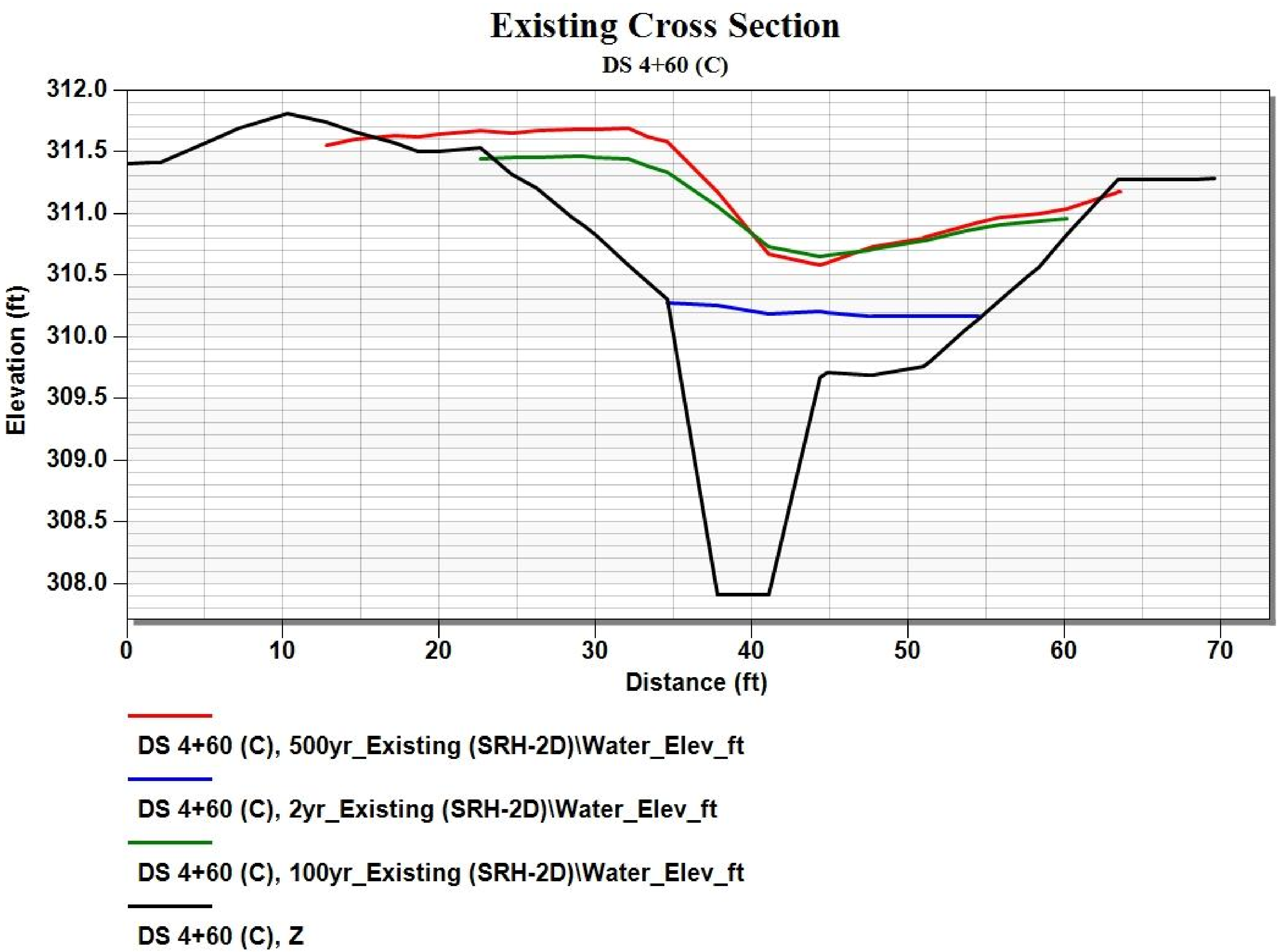


Figure H.47: Existing conditions cross section at downstream station 4+60 (C)

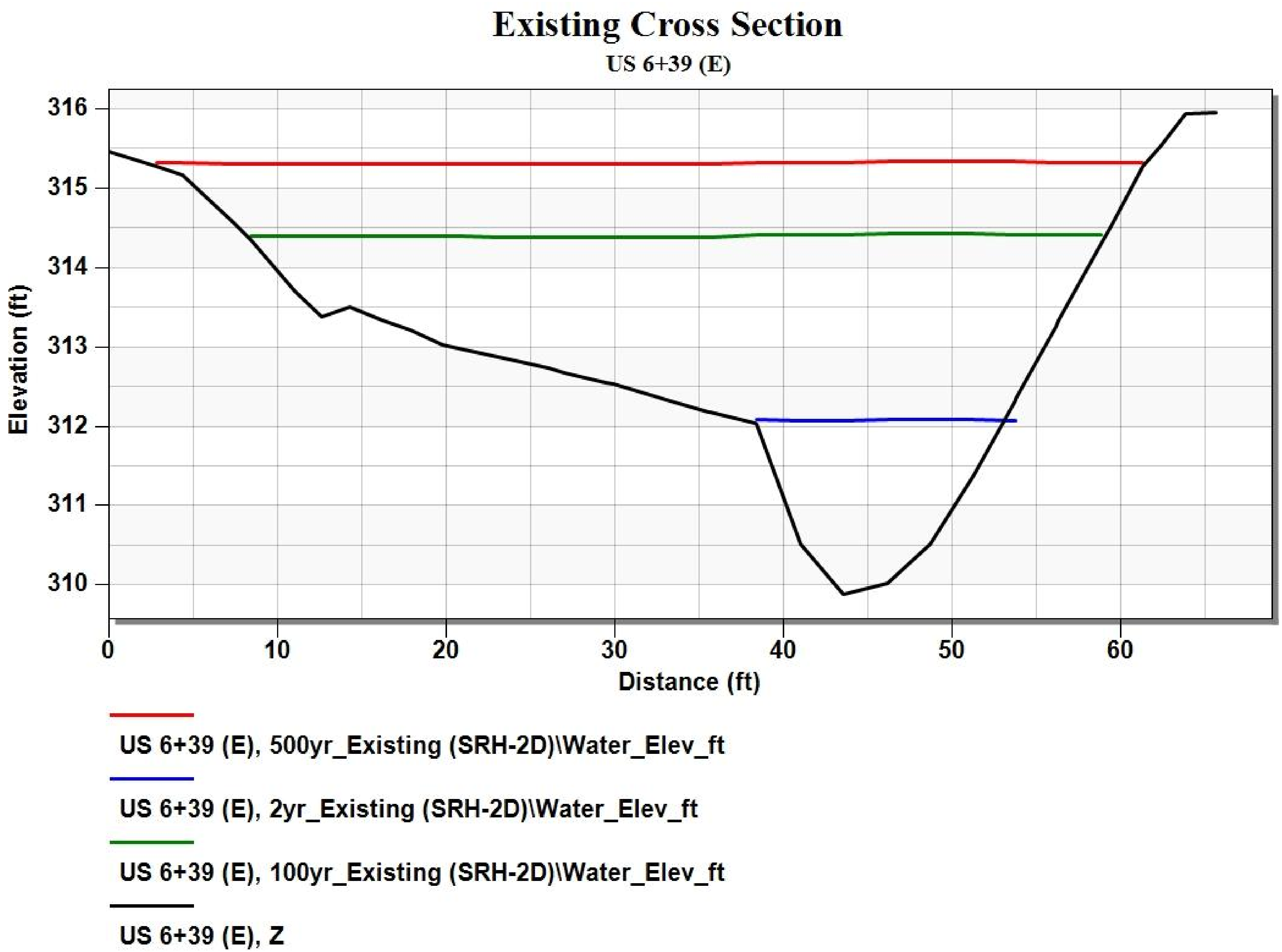


Figure H.48: Existing conditions cross section at upstream station 6+39 (E)

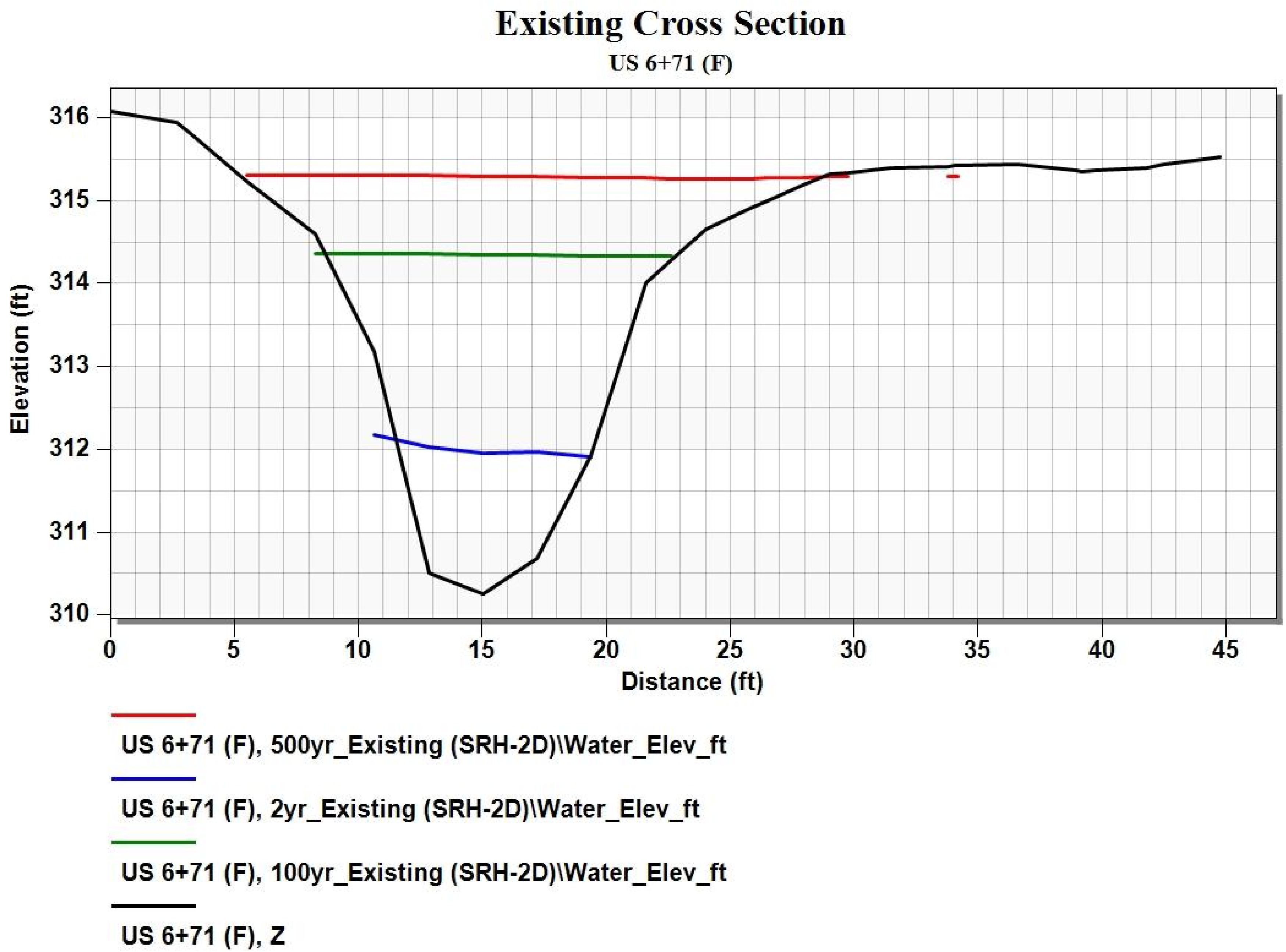


Figure H.49: Existing conditions cross section at upstream station 6+71 (F)

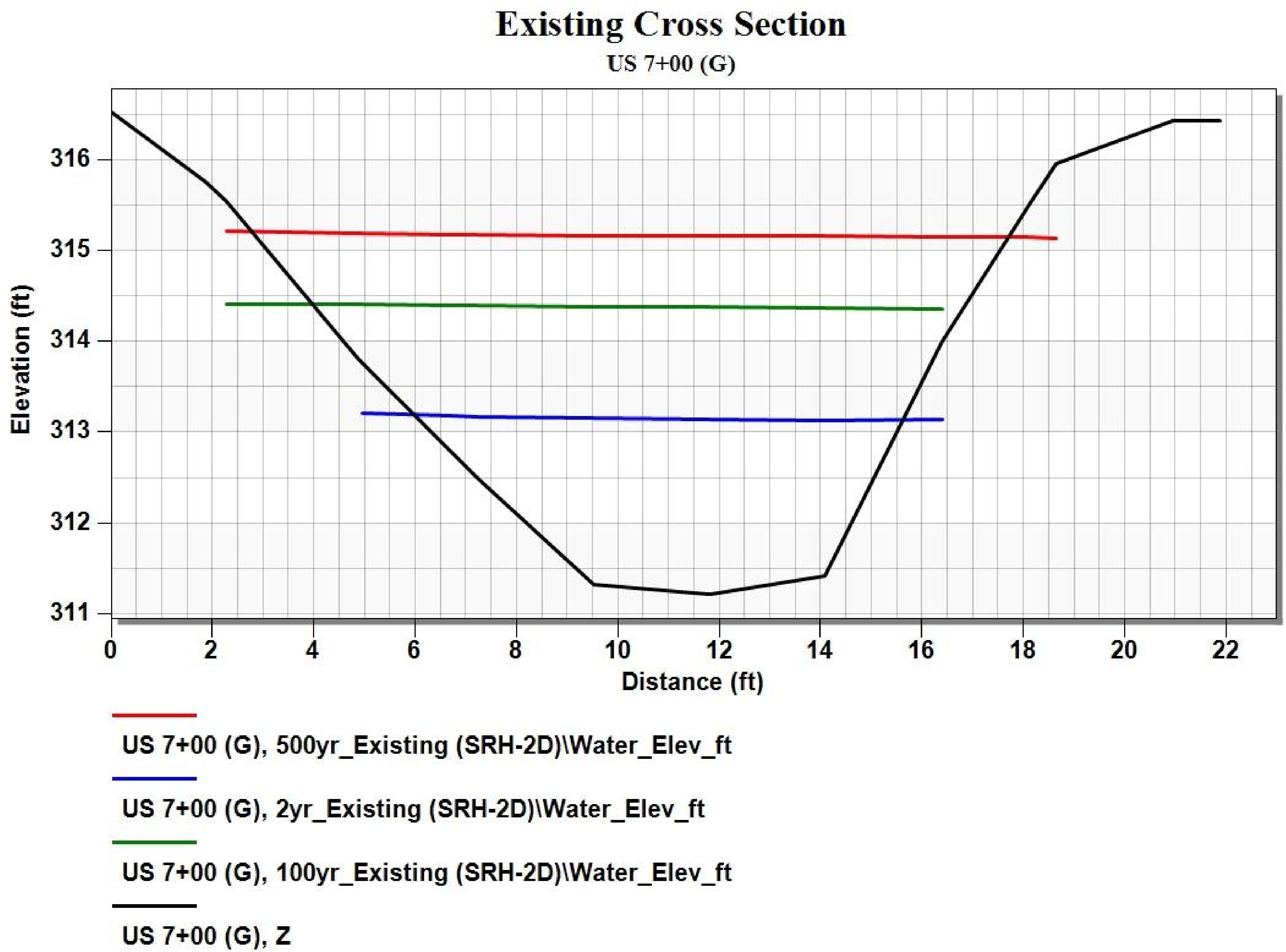


Figure H.50: Existing conditions cross section at upstream station 7+00 (G)

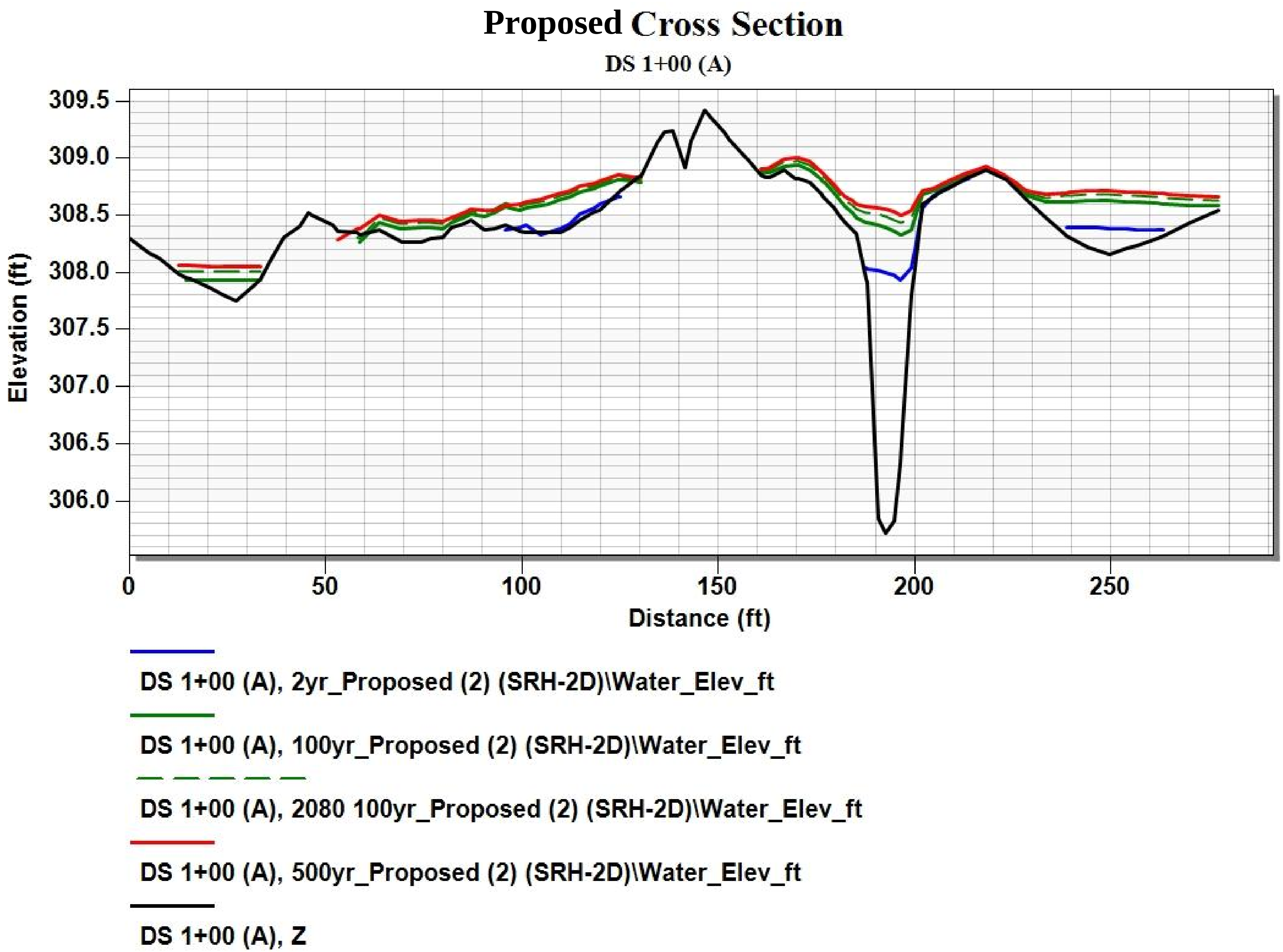


Figure H.51: Proposed conditions cross section at downstream station 10+00 (A)

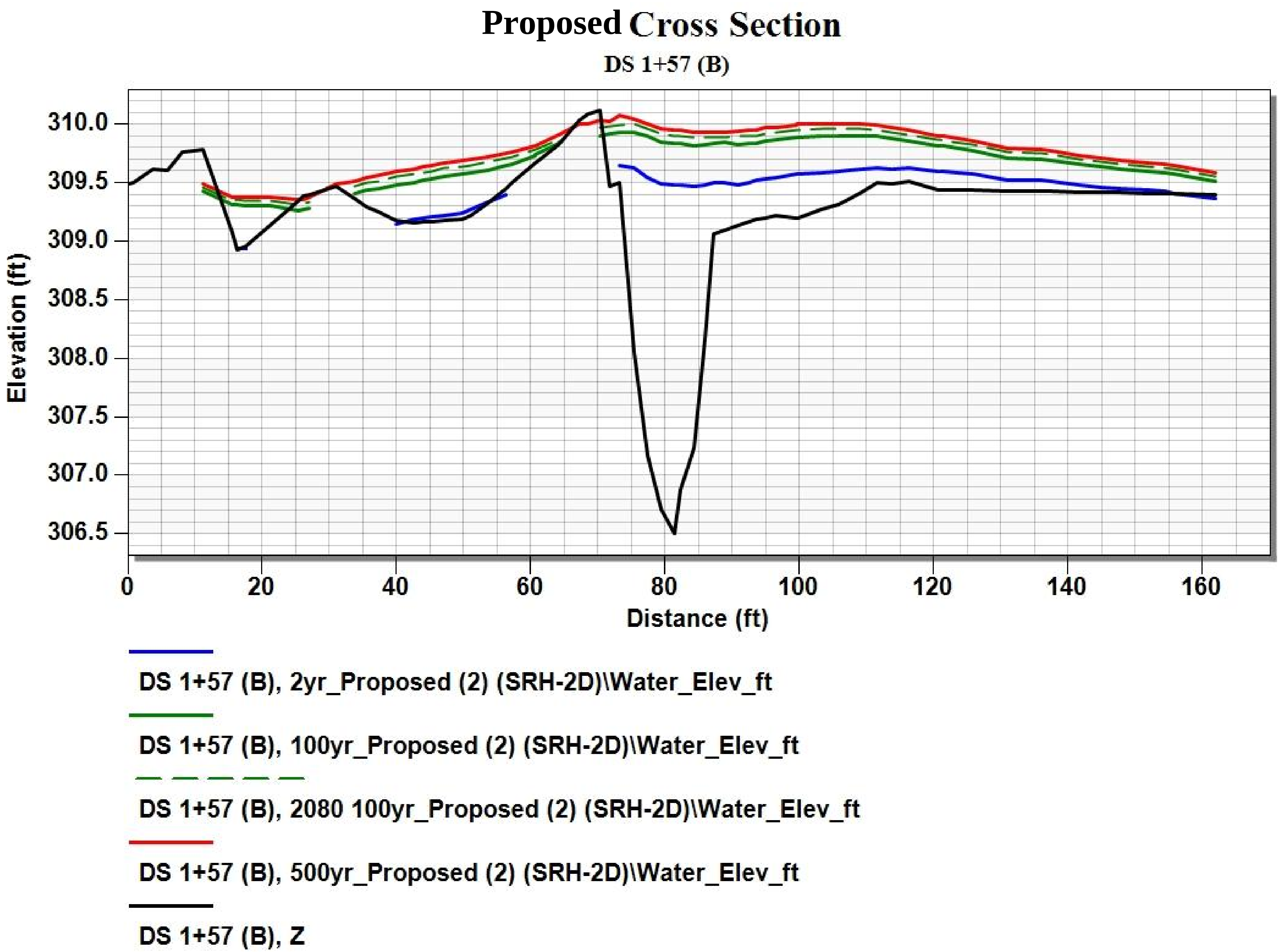


Figure H.52: Proposed conditions cross section at downstream station 10+57 (B)

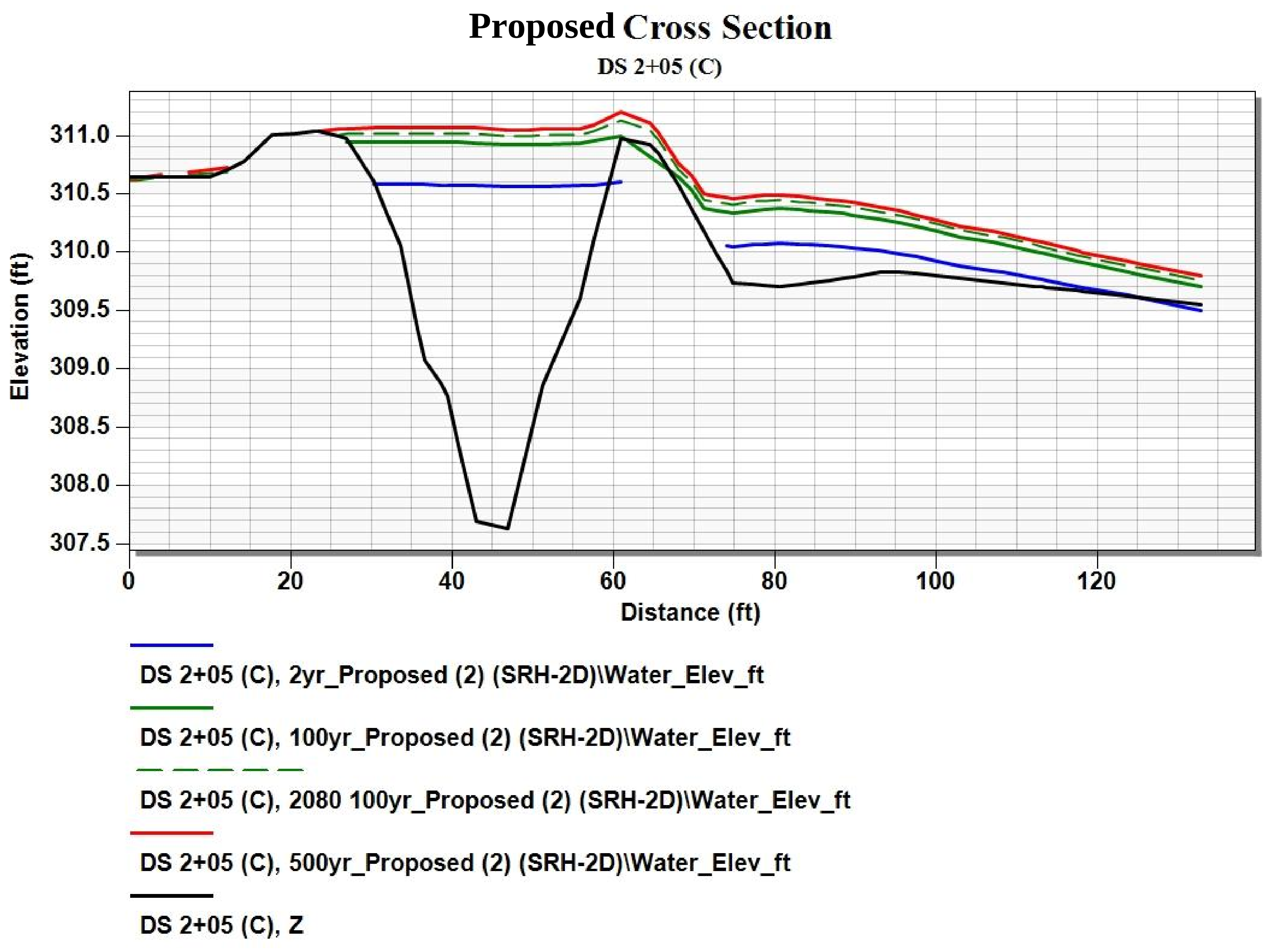


Figure H.53: Proposed conditions cross section at downstream station 11+05 (C)

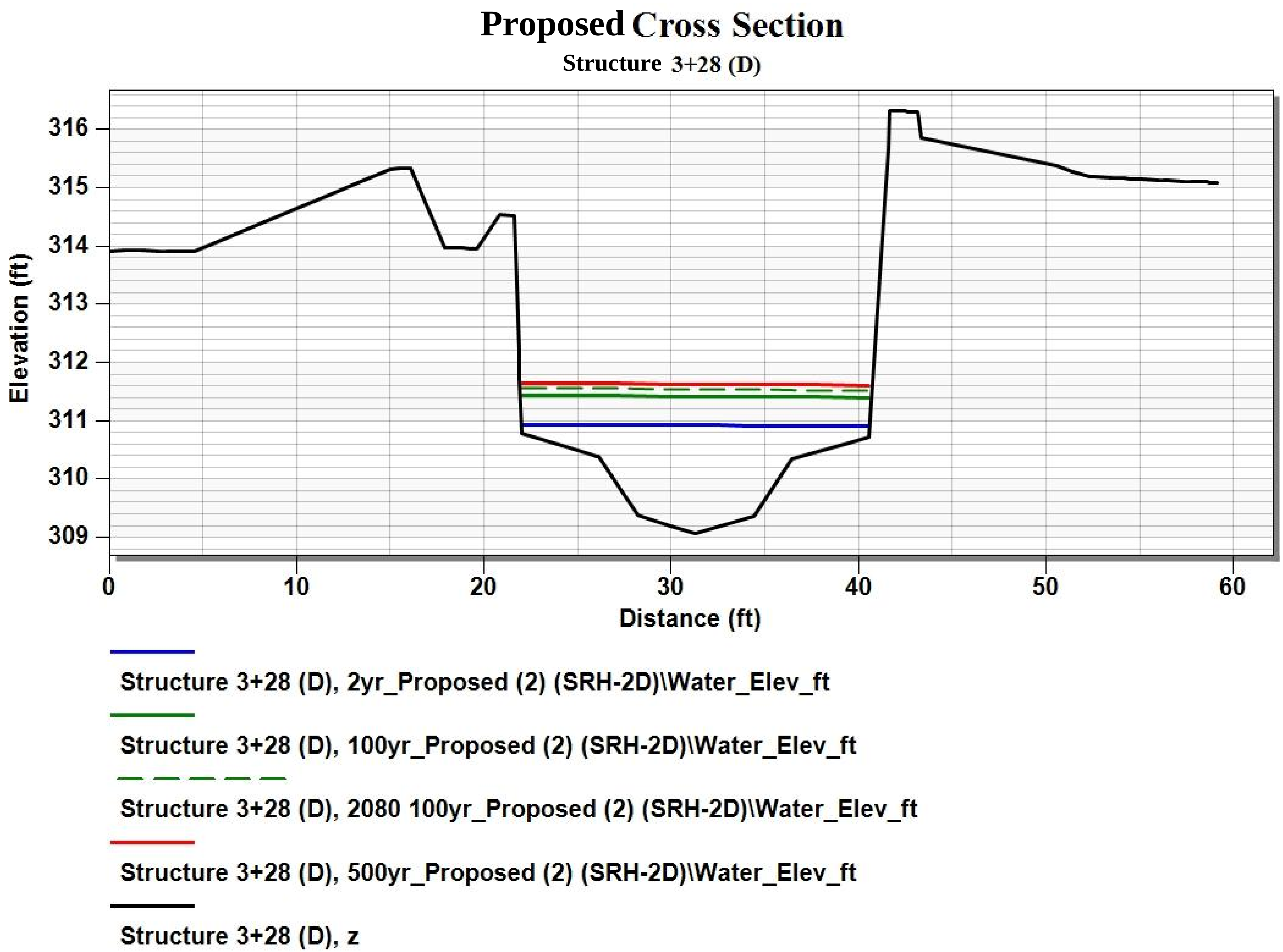


Figure H.54: Proposed conditions cross section at the structure 12+28 (D)

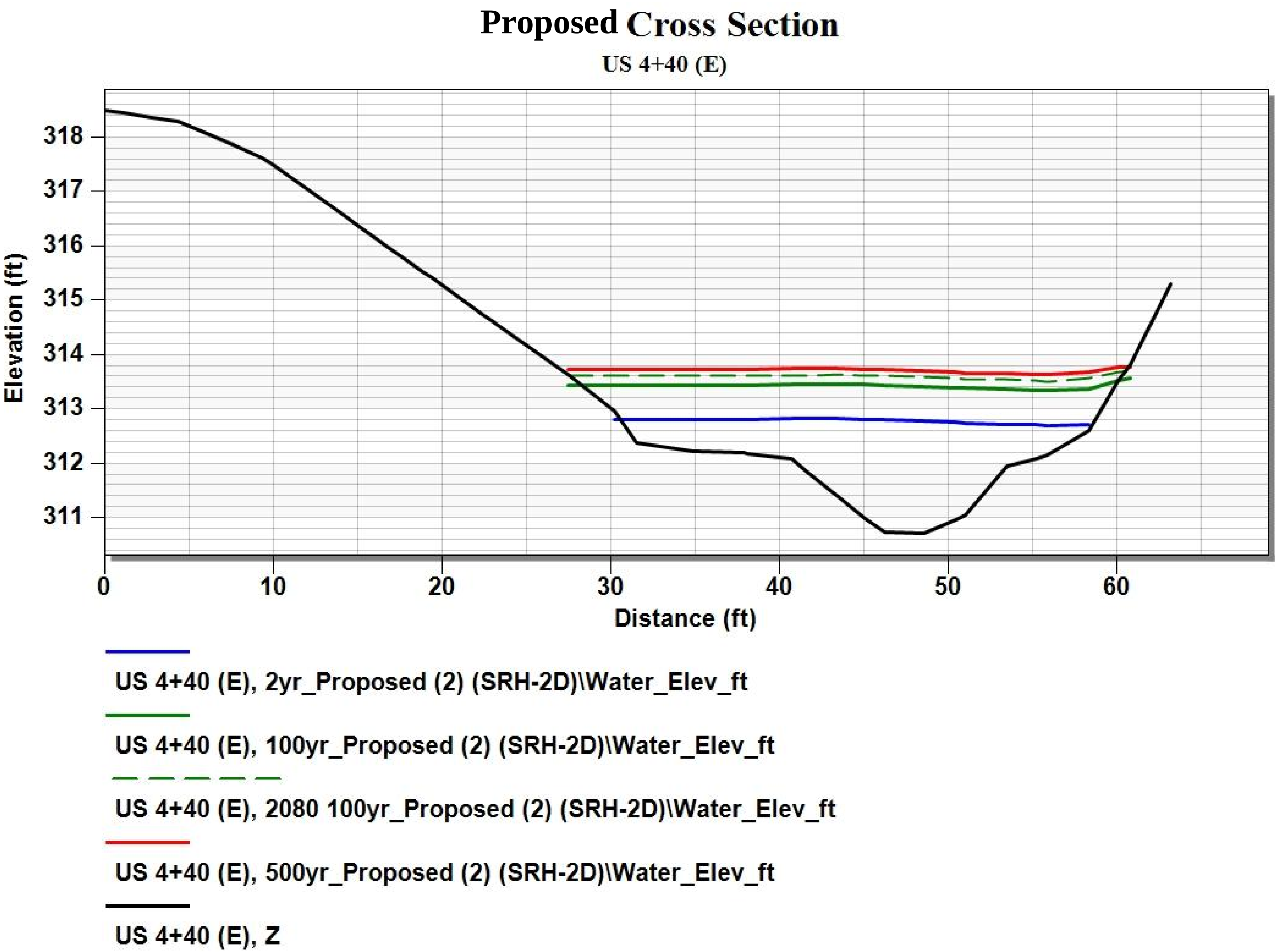


Figure H.55: Proposed conditions cross section at upstream station 13+40 (E)

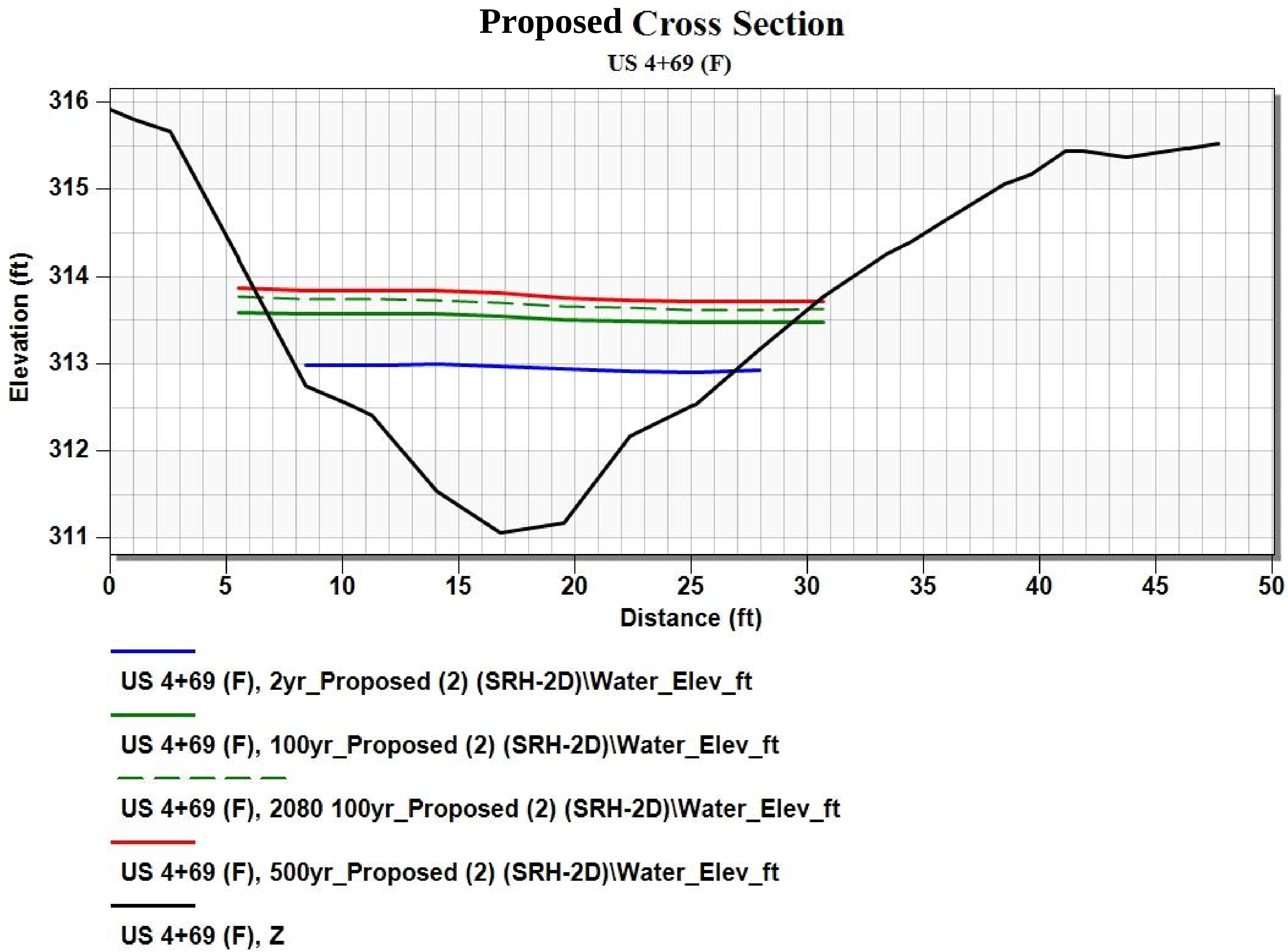


Figure H.56: Proposed conditions cross section at upstream station 13+69 (F)

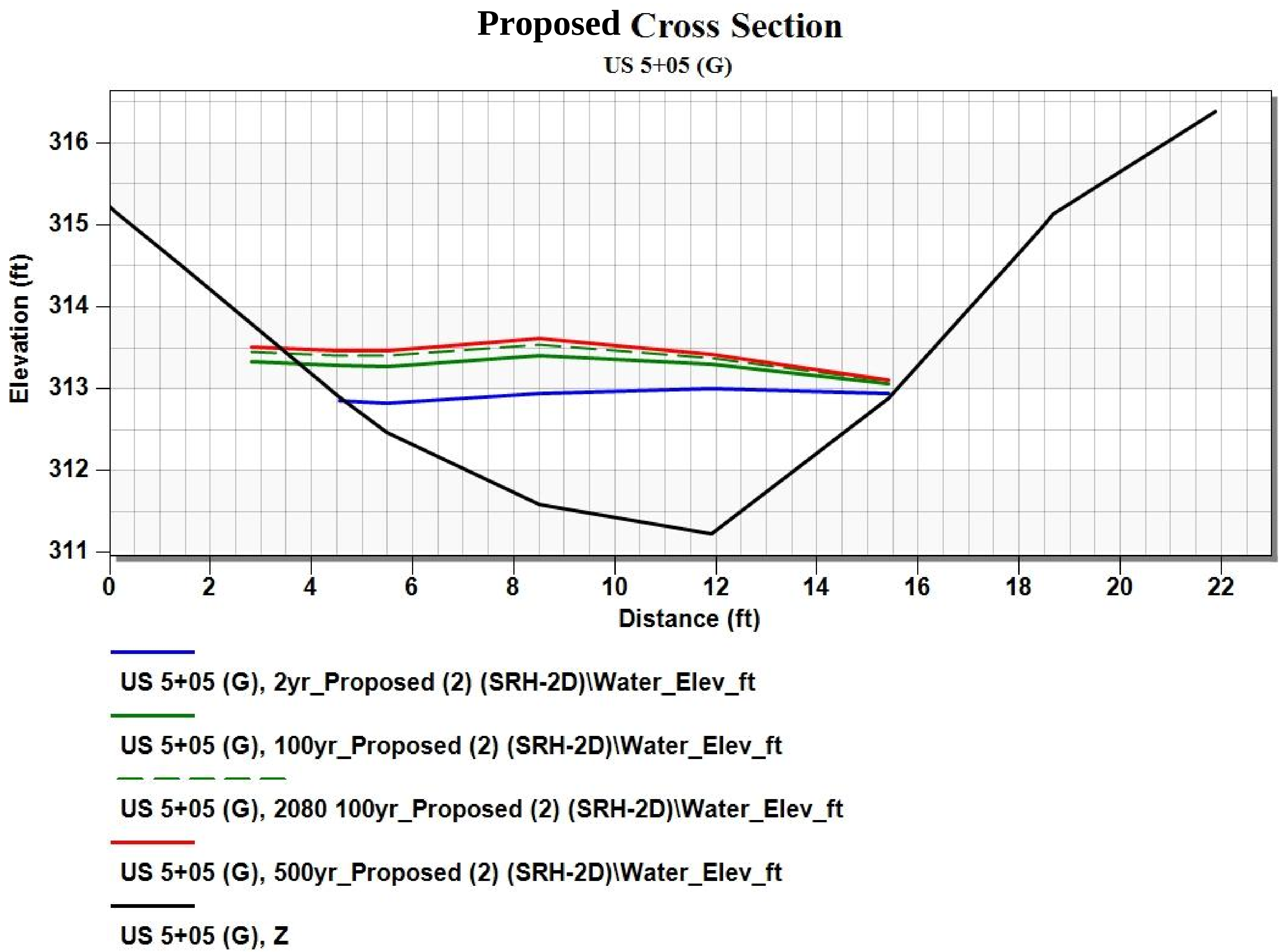


Figure H.57: Proposed conditions cross section at upstream station 14+05 (G)

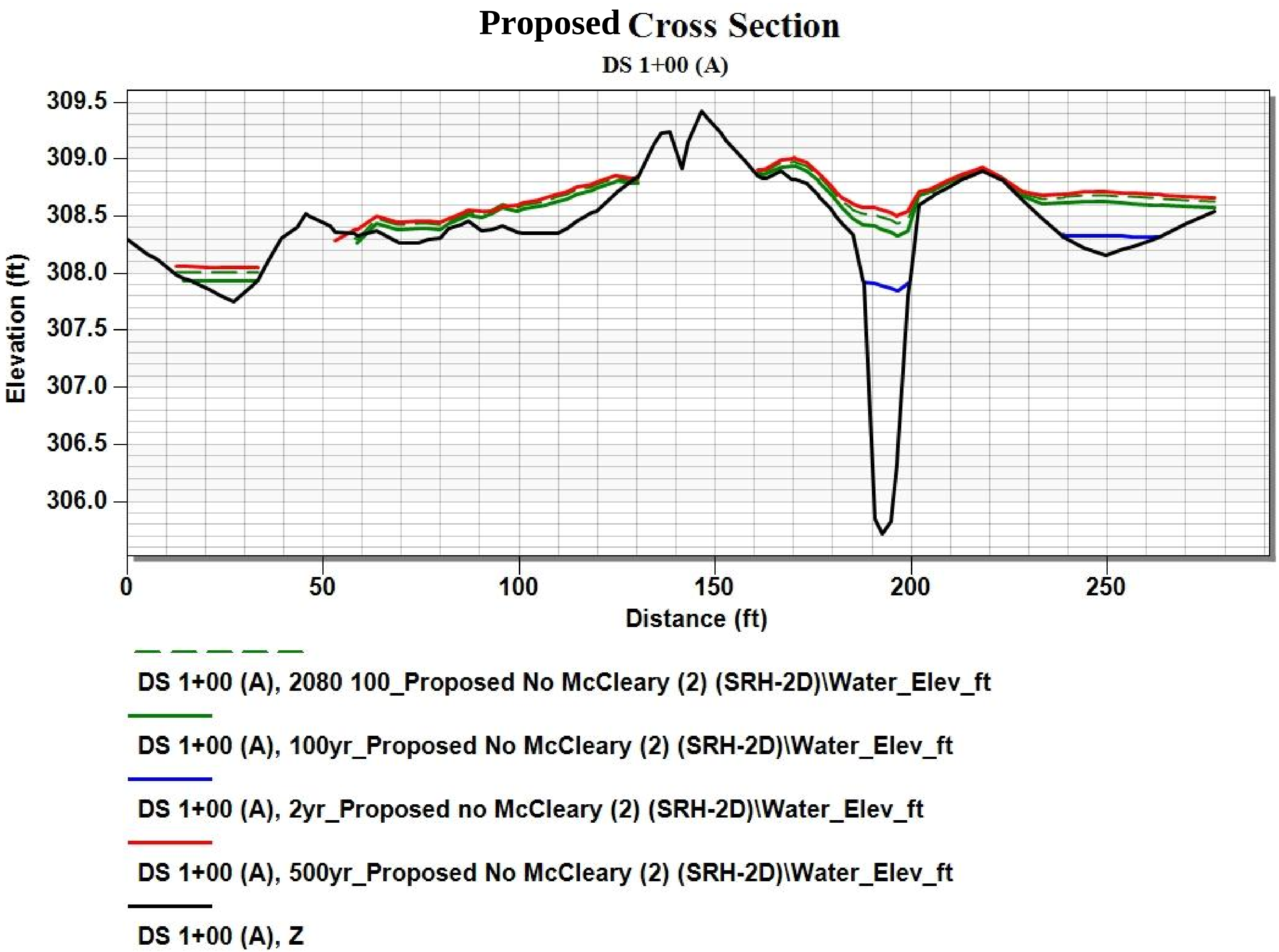


Figure H.58: Proposed conditions no McCleary culvert cross section at downstream station 10+00 (A)

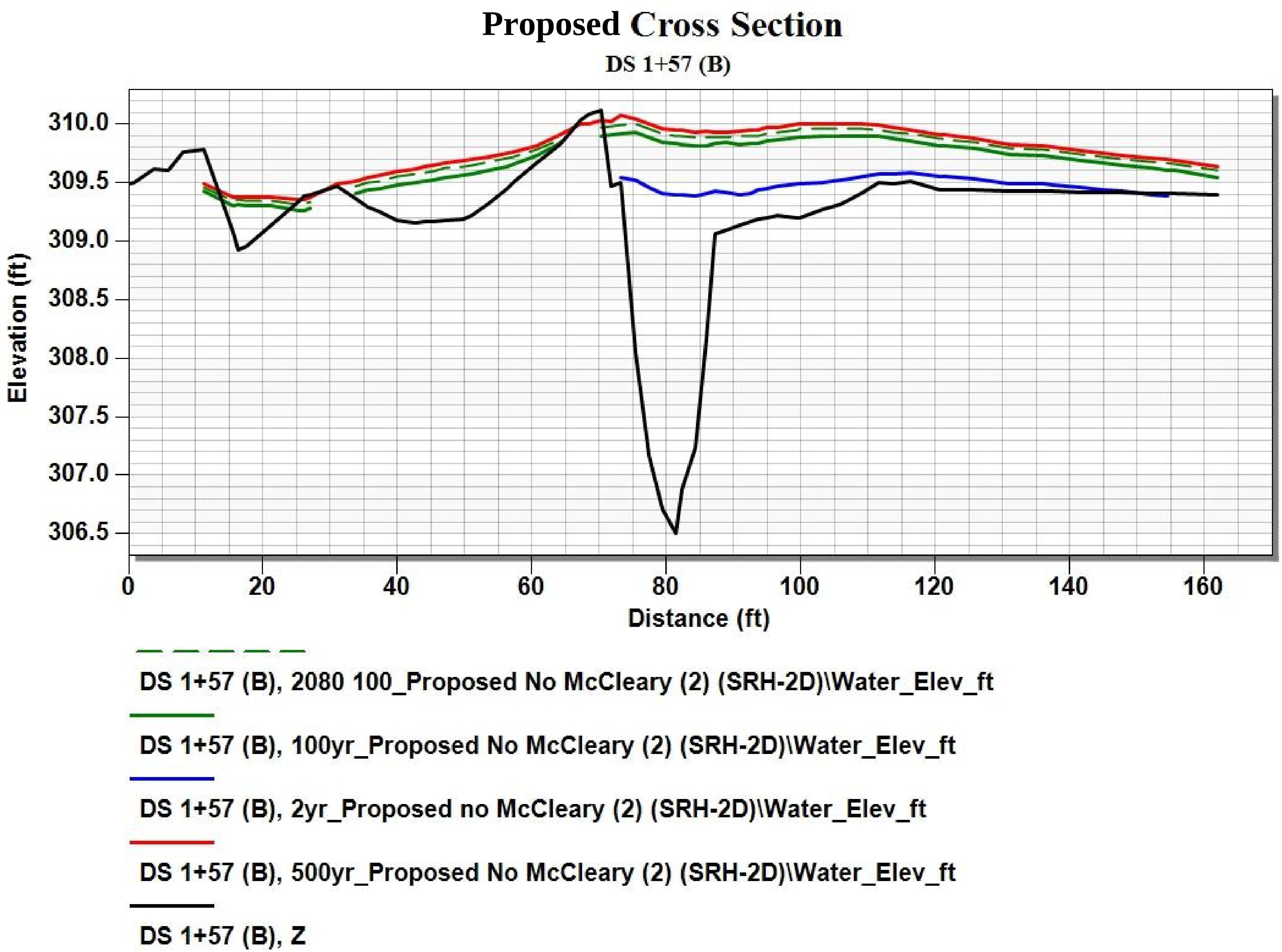


Figure H.59: Proposed conditions no McCleary culvert cross section at downstream station 10+57 (B)

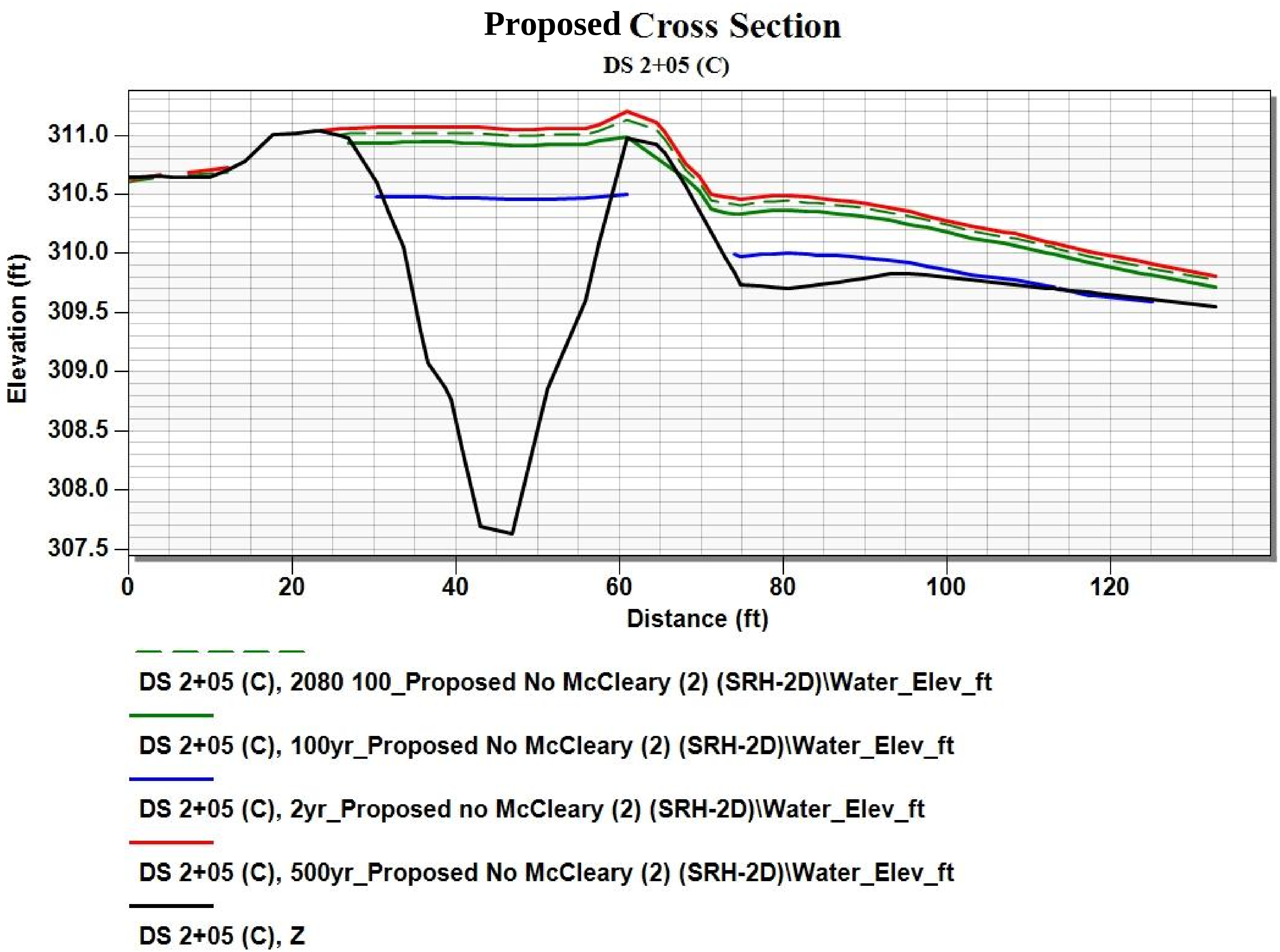


Figure H.60: Proposed conditions no McCleary culvert cross section at downstream station 11+05 (C)

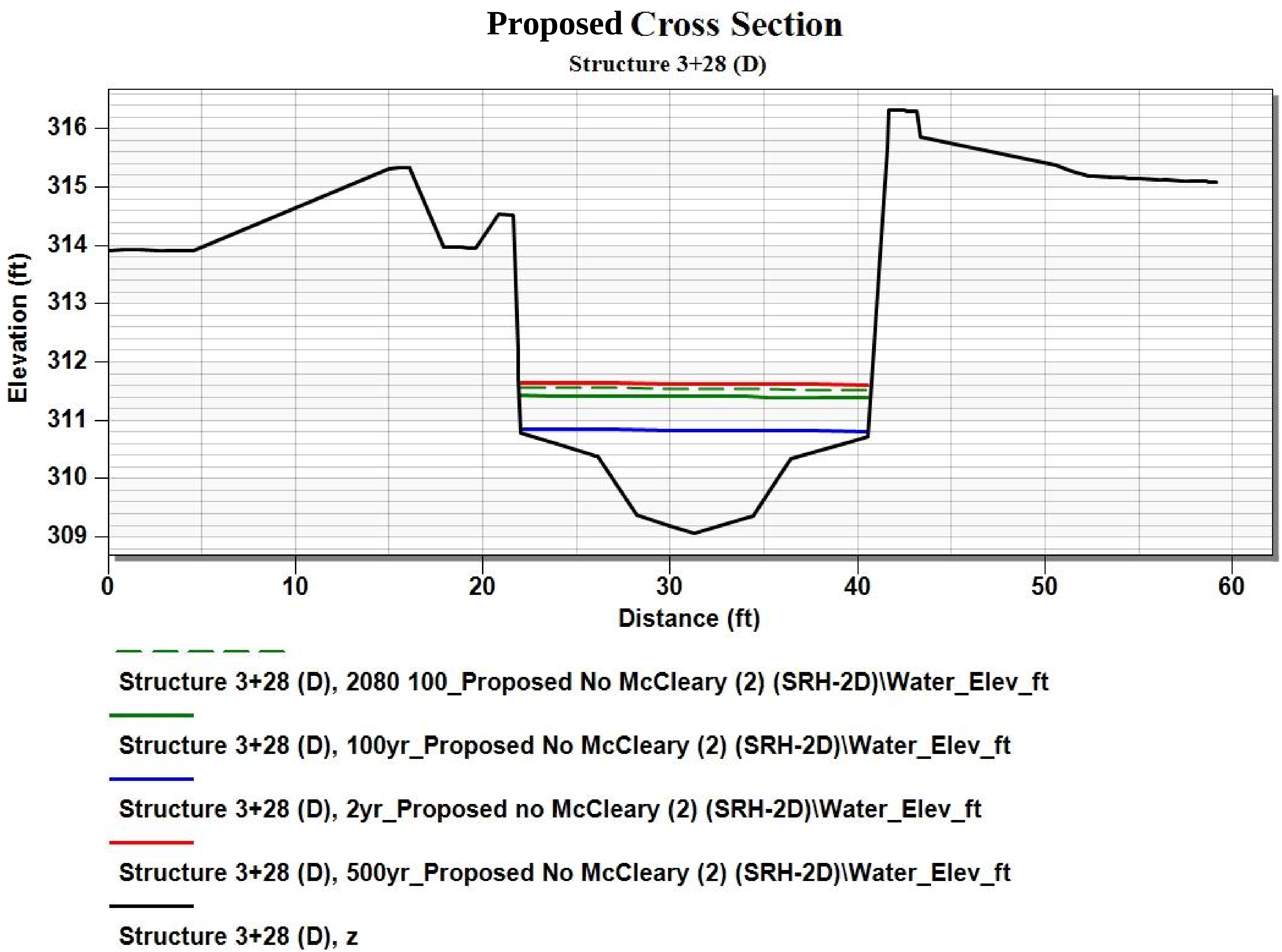


Figure H.61: Proposed conditions no McCleary culvert cross section at the structure 12+28 (D)

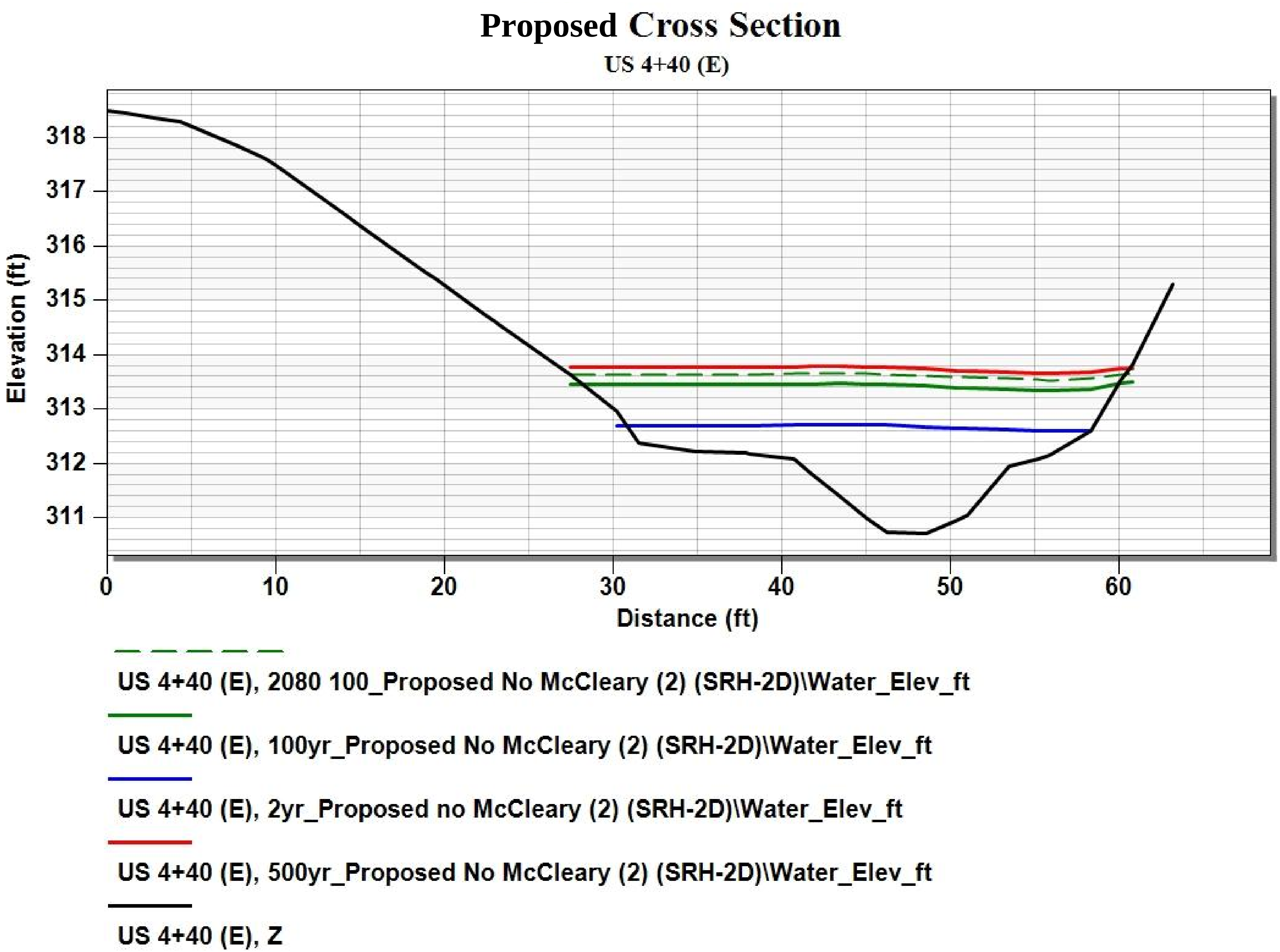


Figure H.62: Proposed conditions no McCleary culvert cross section at upstream station 13+40 (E)

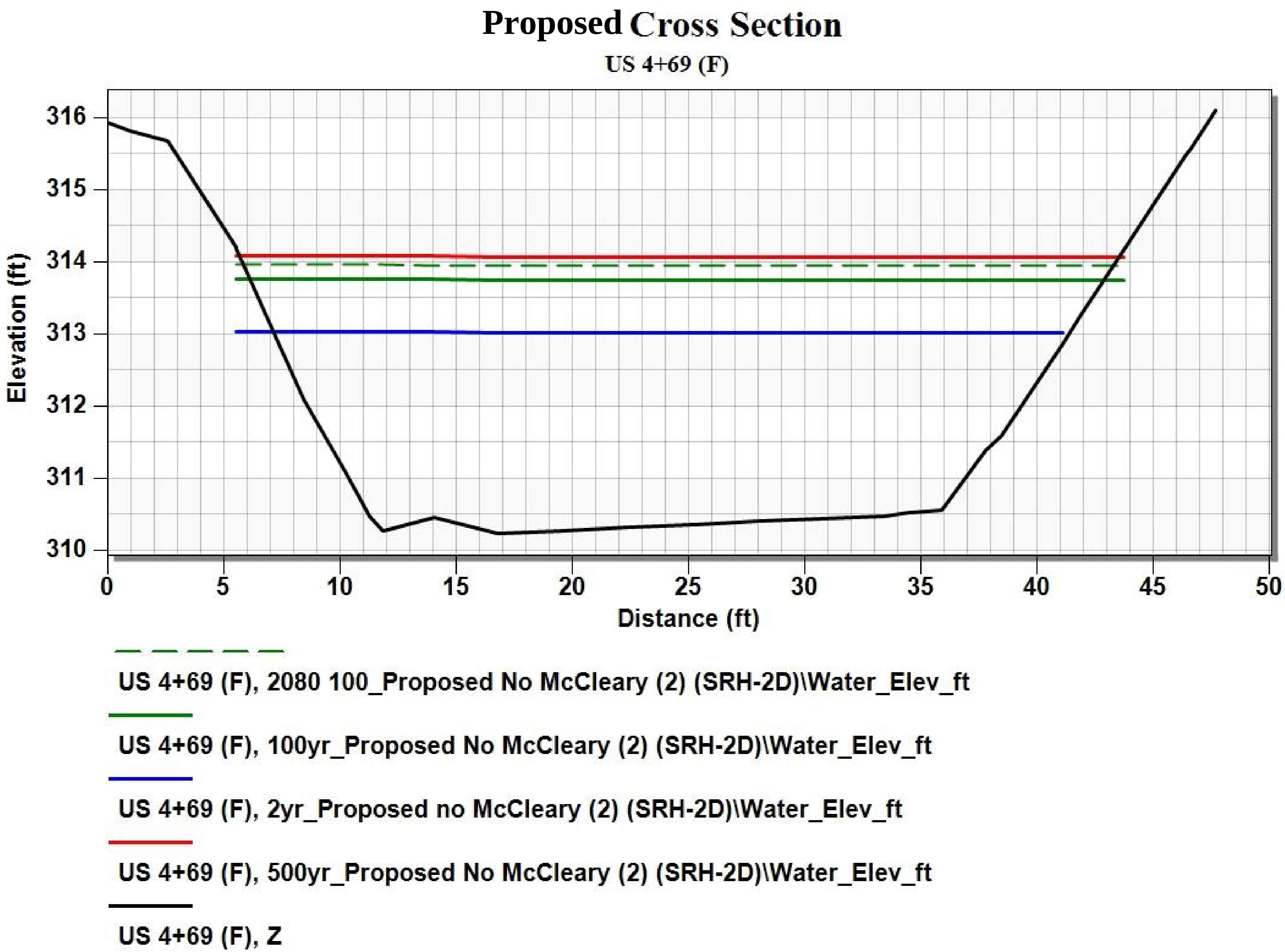


Figure H.63: Proposed conditions no McCleary culvert cross section at upstream station 13+69 (F)

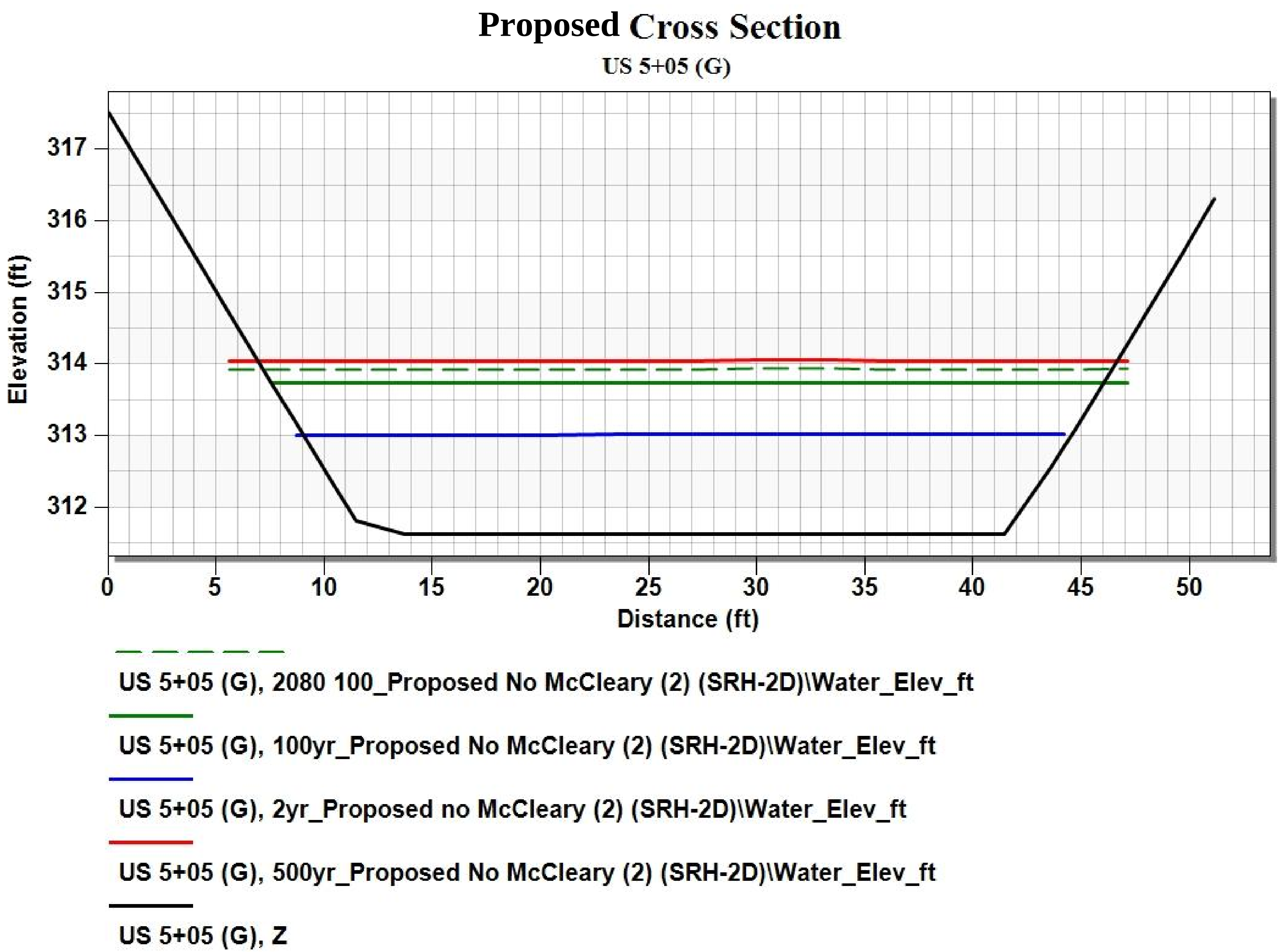


Figure H.64: Proposed conditions no McCleary culvert cross section at upstream station 14+05 (G)

Appendix I: SRH-2D Model Stability and Continuity

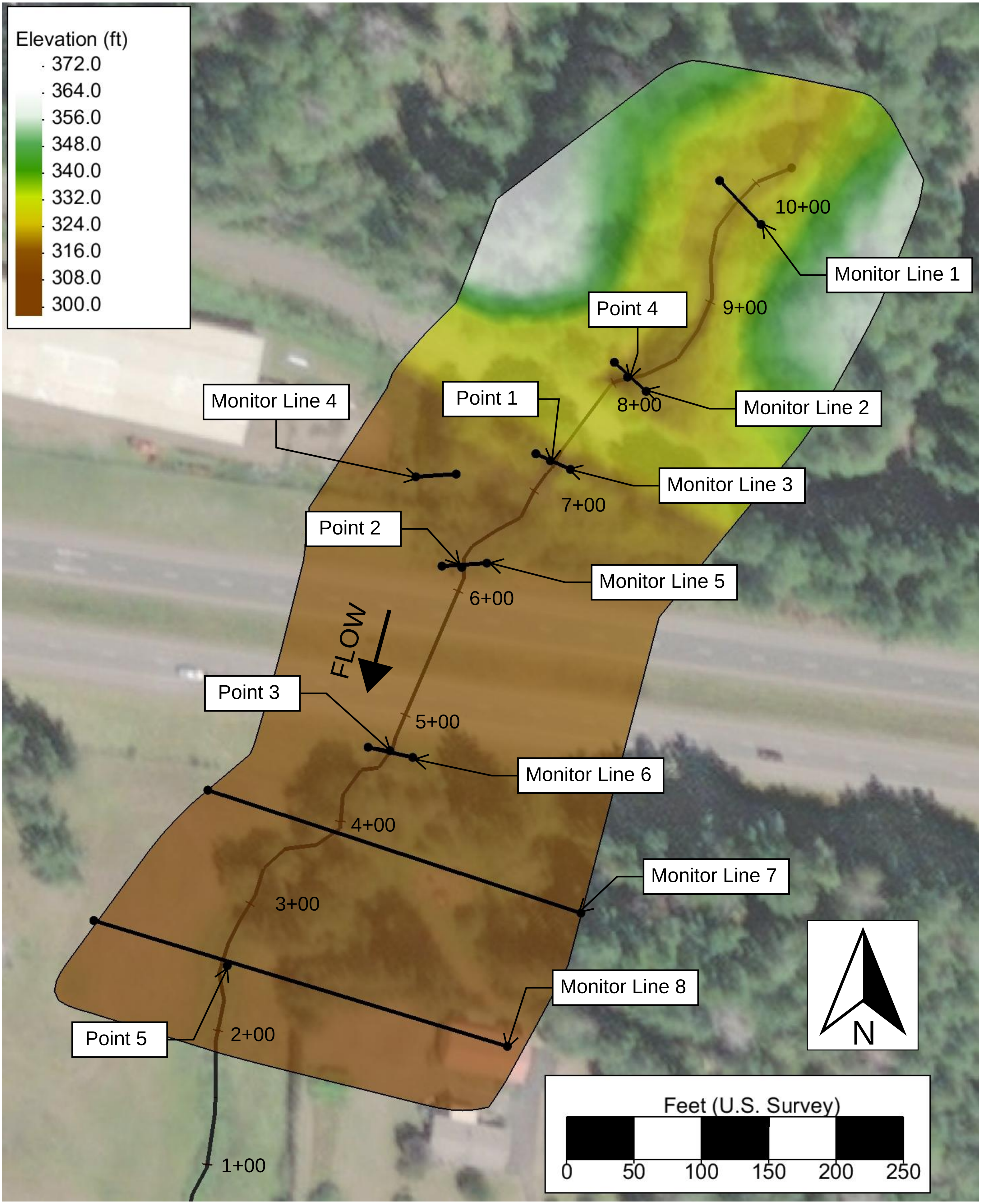


Figure I.1: Existing conditions monitor points and lines

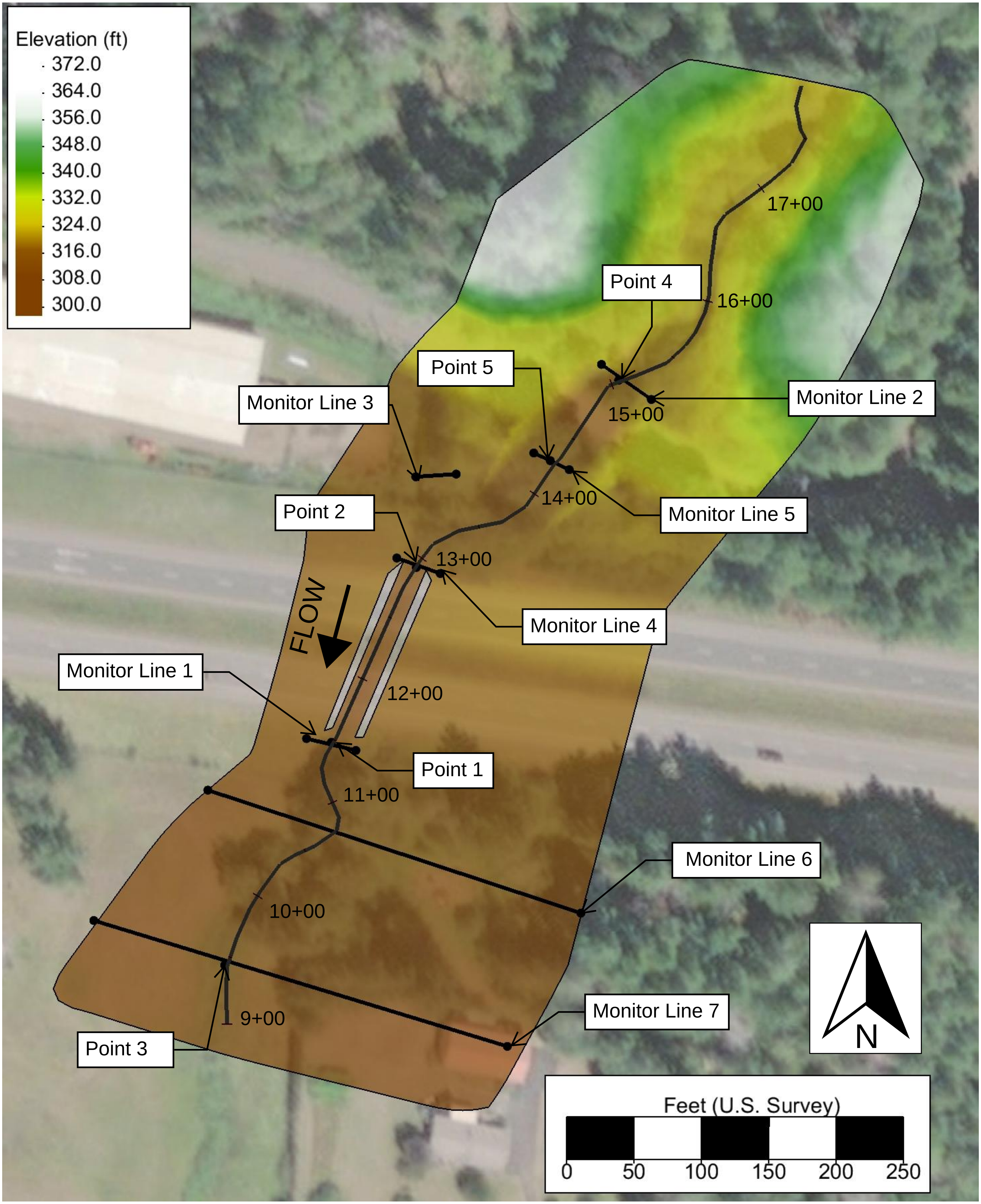


Figure I.2: Proposed conditions monitor points and lines

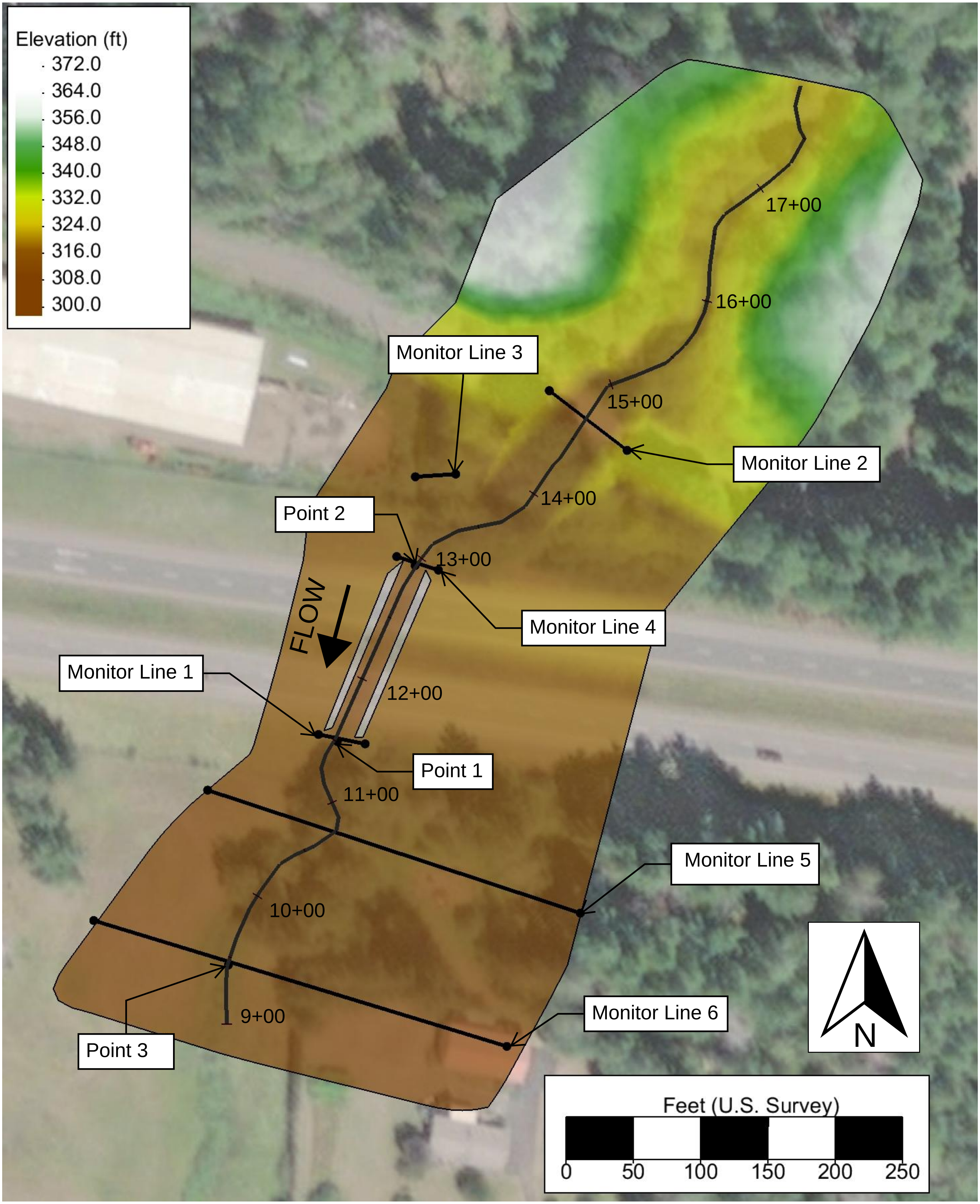


Figure I.3: Proposed conditions no McCleary Culvert monitor points and lines

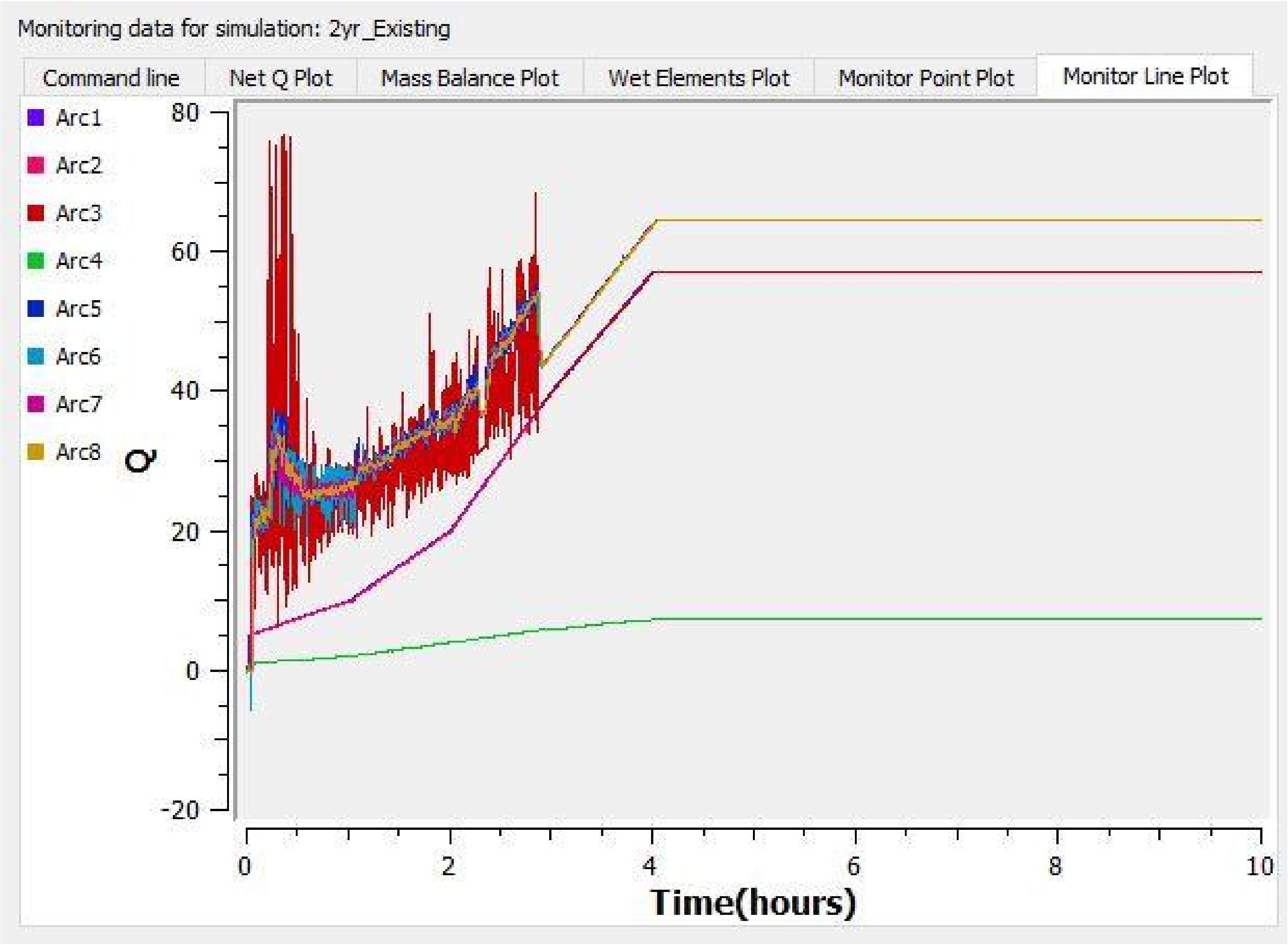


Figure I.4: Existing conditions 2-year monitor lines

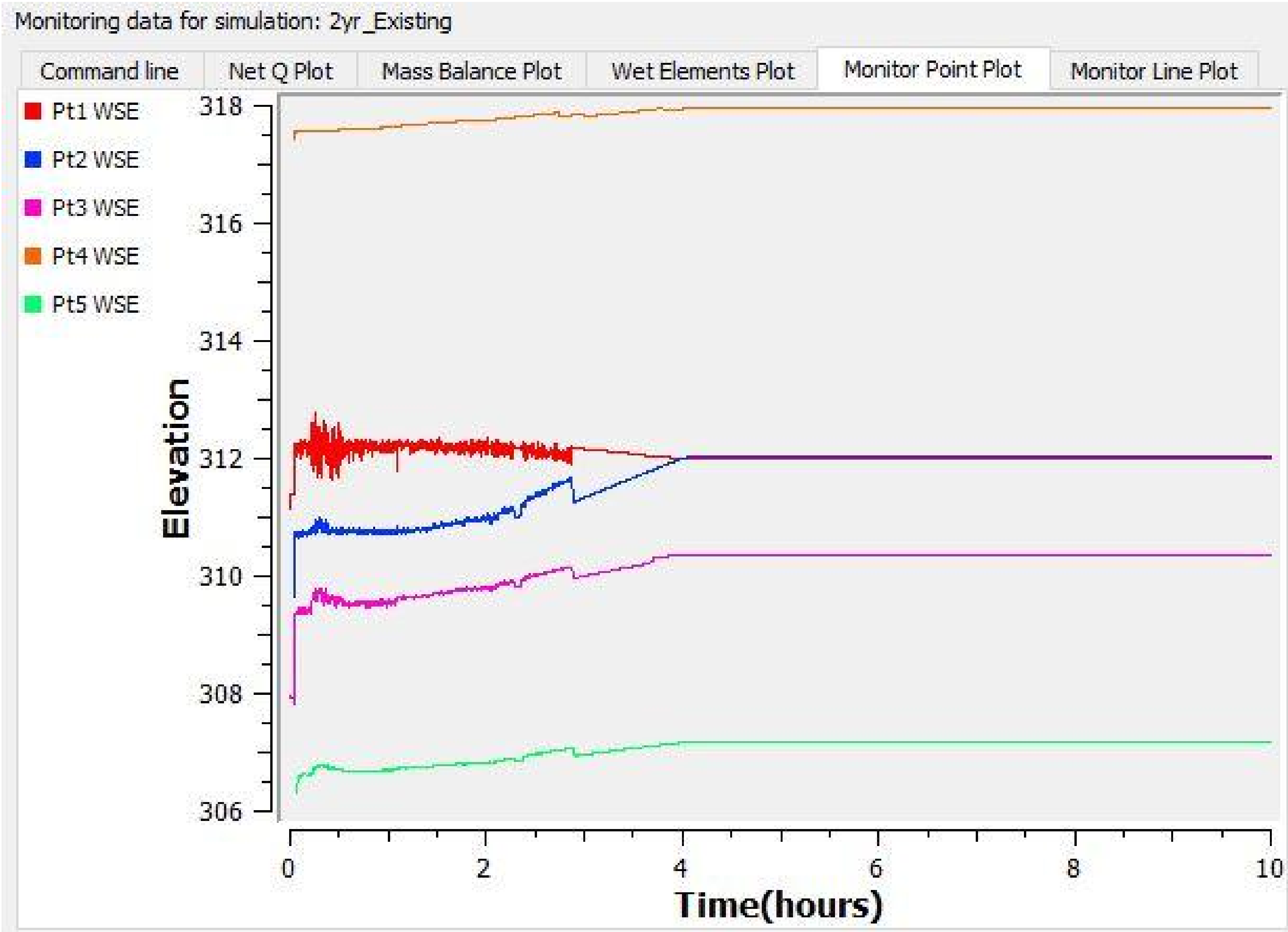


Figure I.5: Existing conditions 2-year monitor points

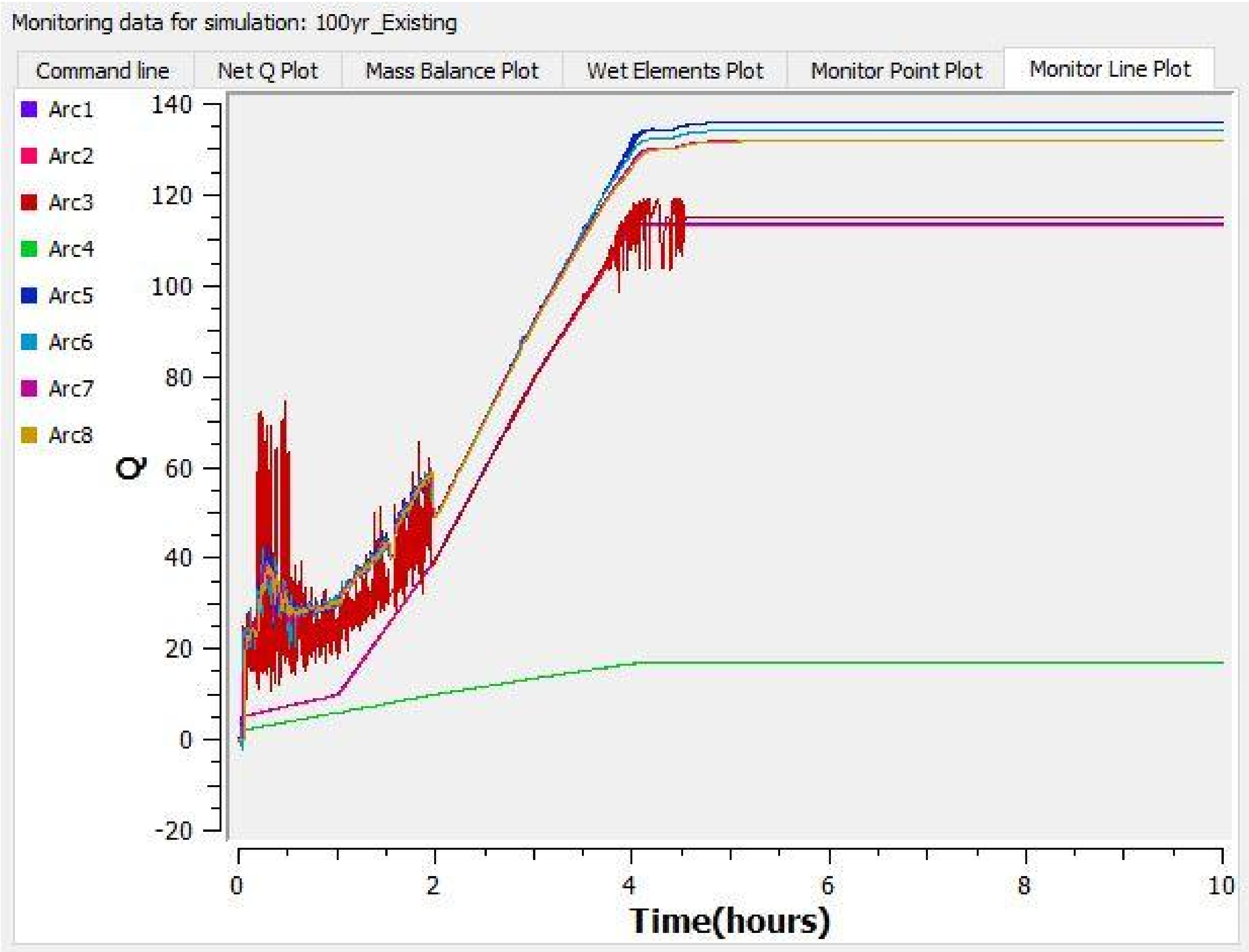


Figure I.6: Existing conditions 100-year monitor lines

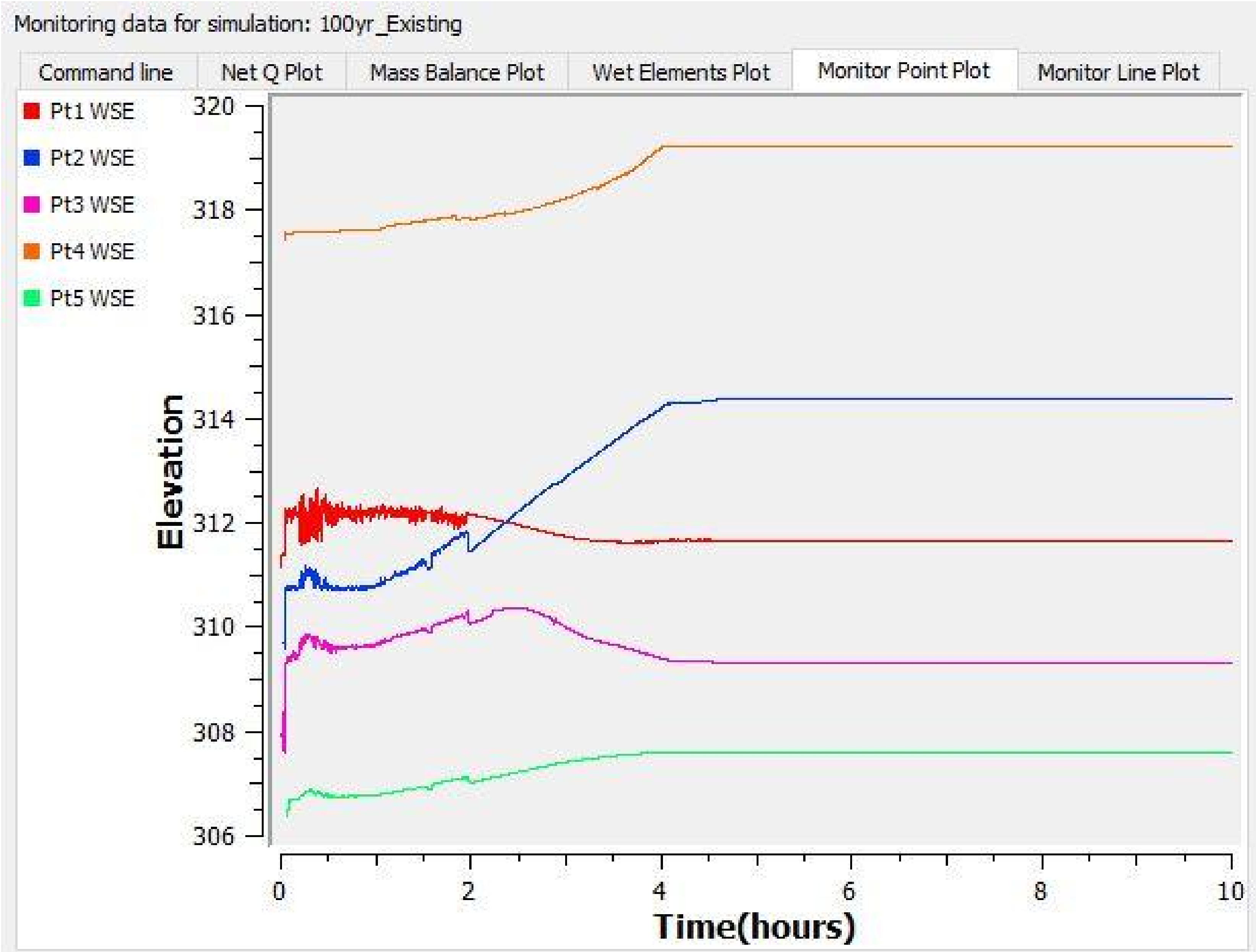


Figure I.7: Existing conditions 100-year monitor points

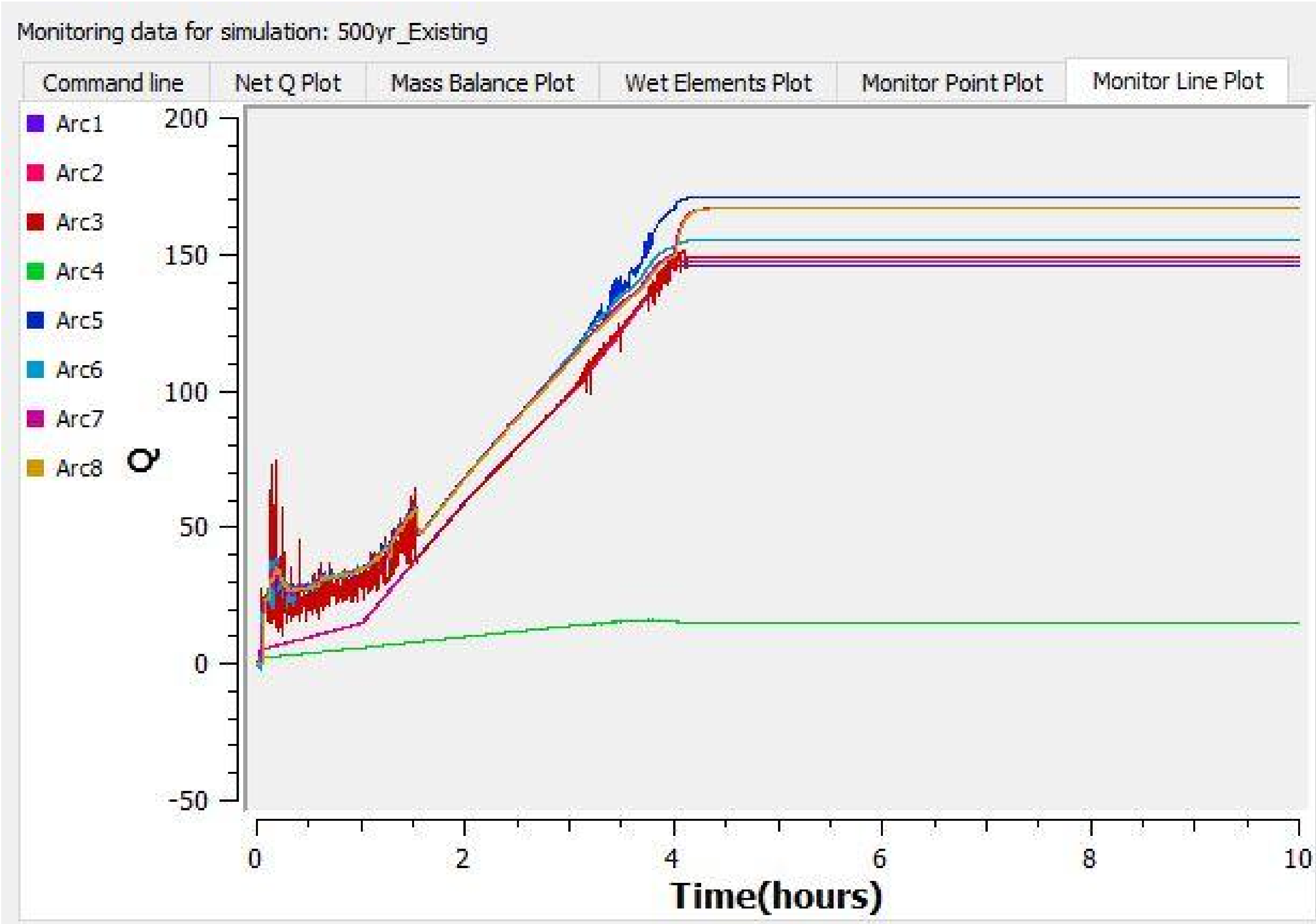


Figure I.8: Existing conditions 500-year monitor lines

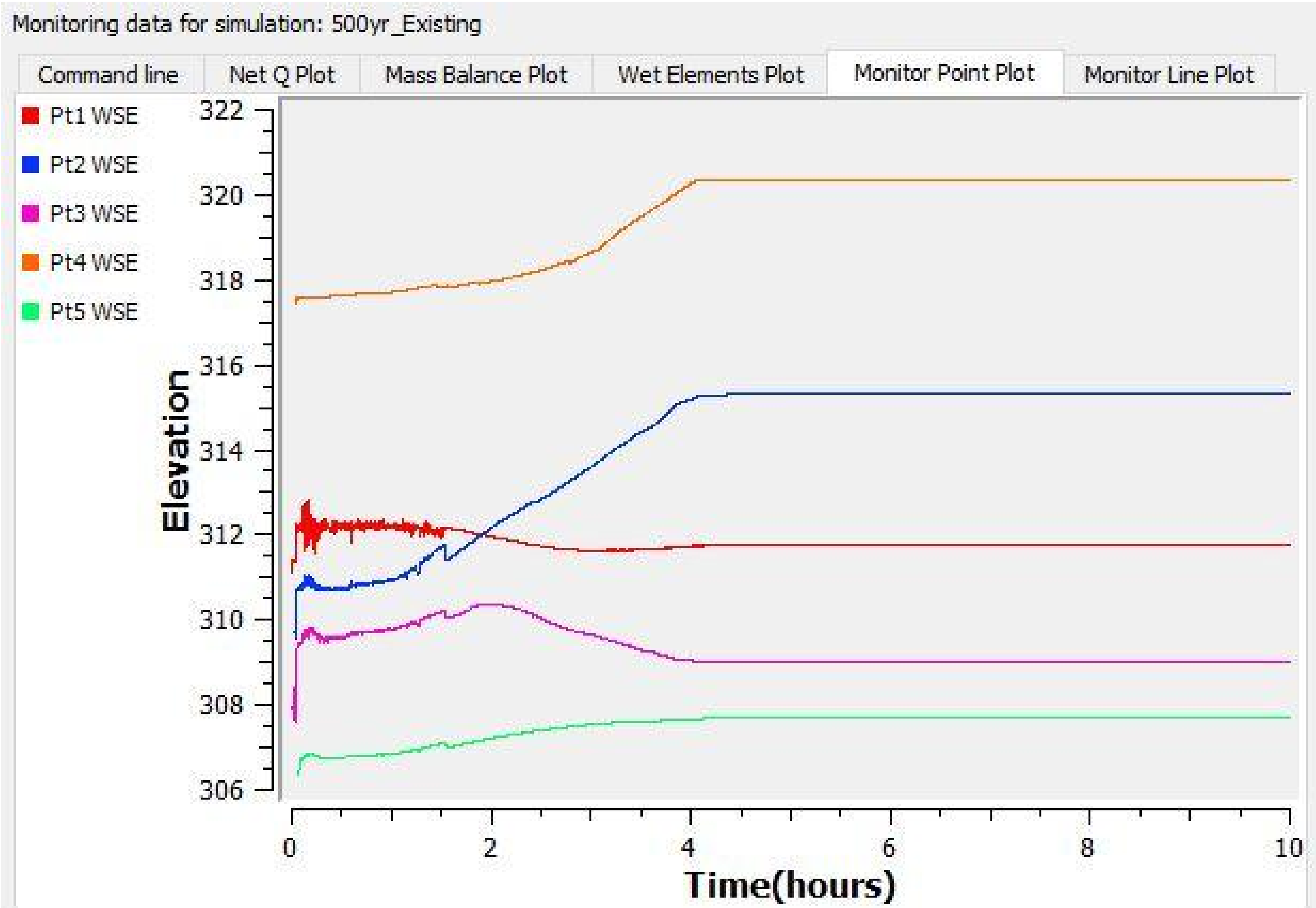


Figure I.9: Existing conditions 500-year monitor points

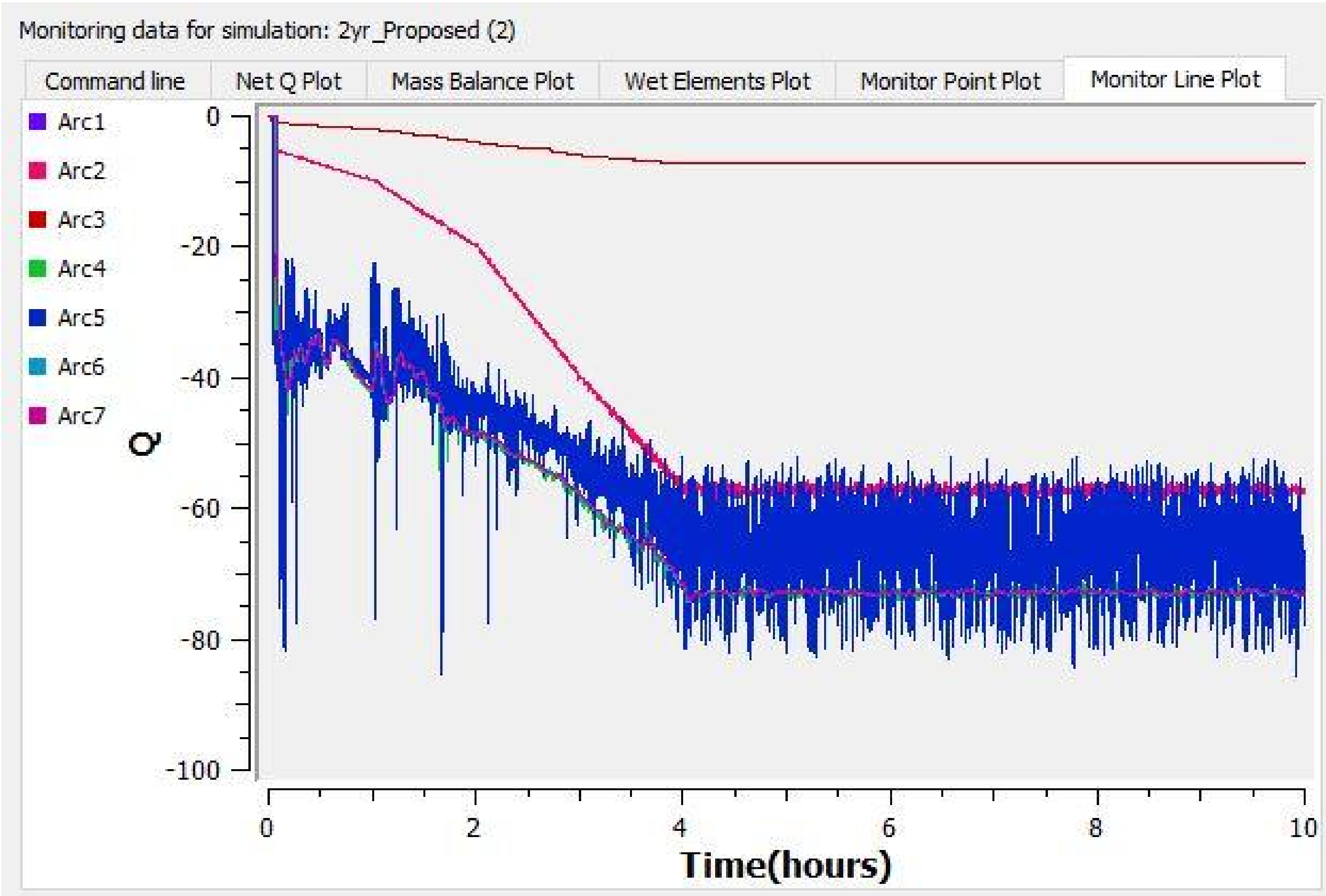


Figure I.10: Proposed conditions 2-year monitor lines

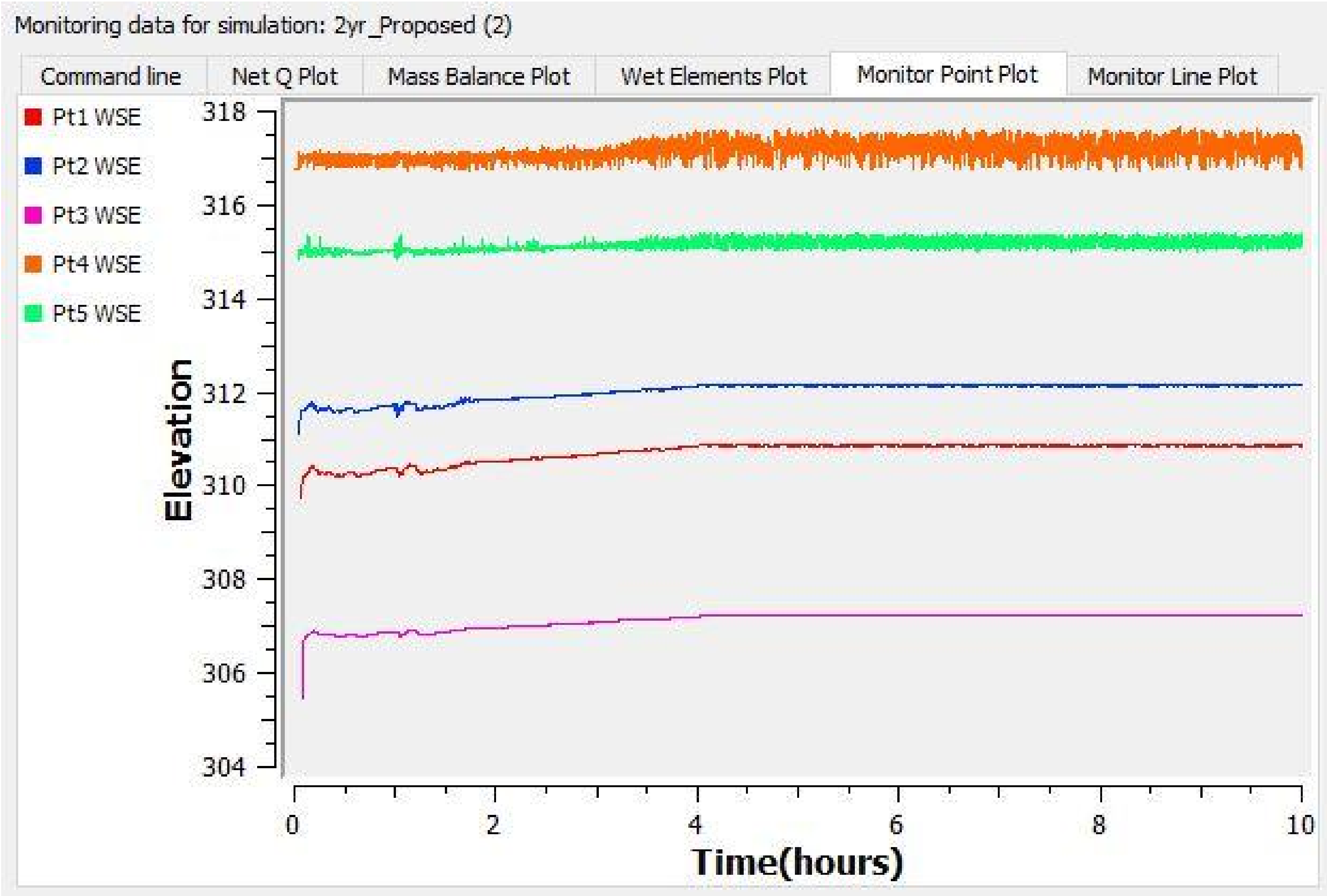


Figure I.11: Proposed conditions 2-year monitor points

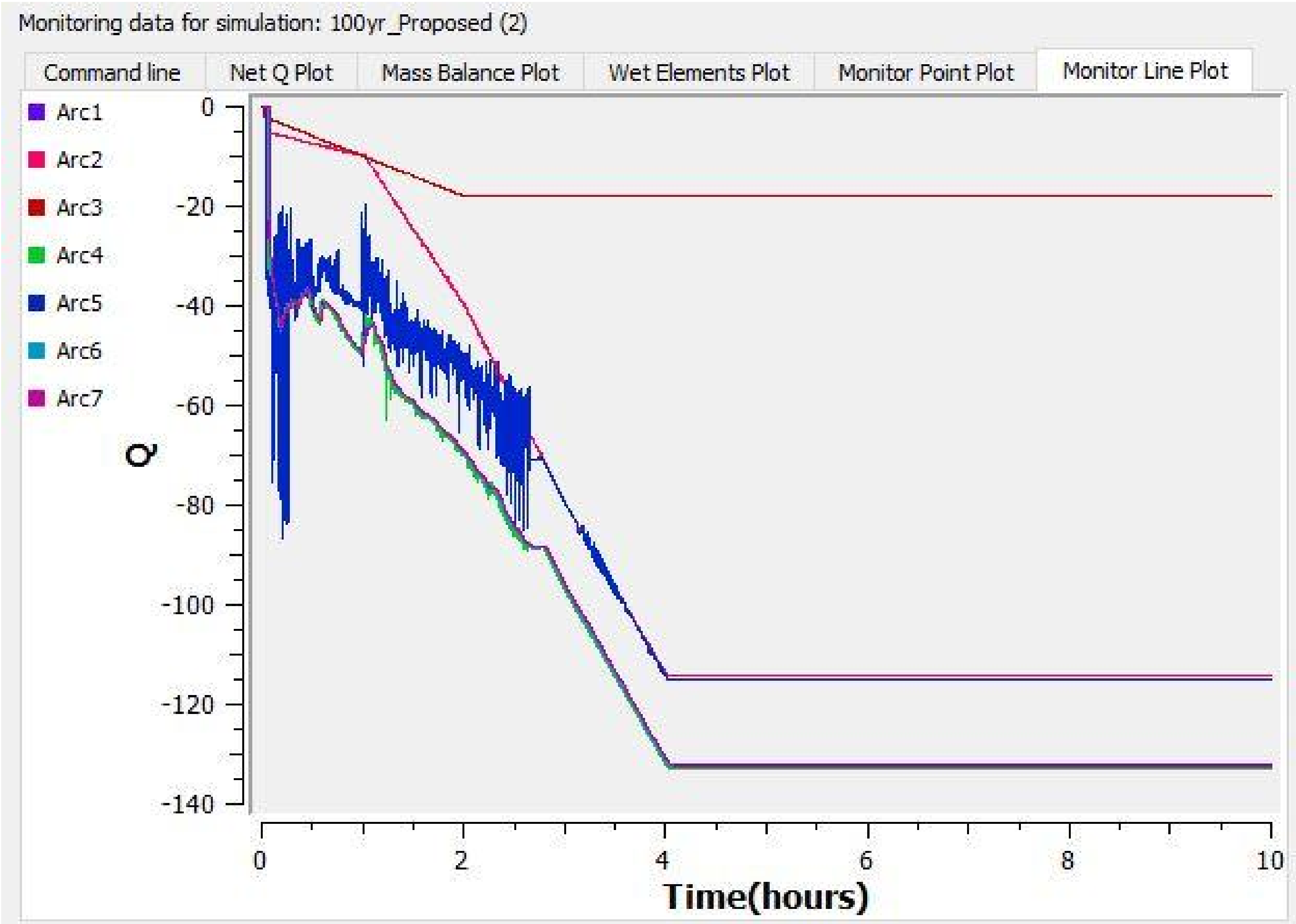


Figure I.12: Proposed conditions 100-year monitor lines

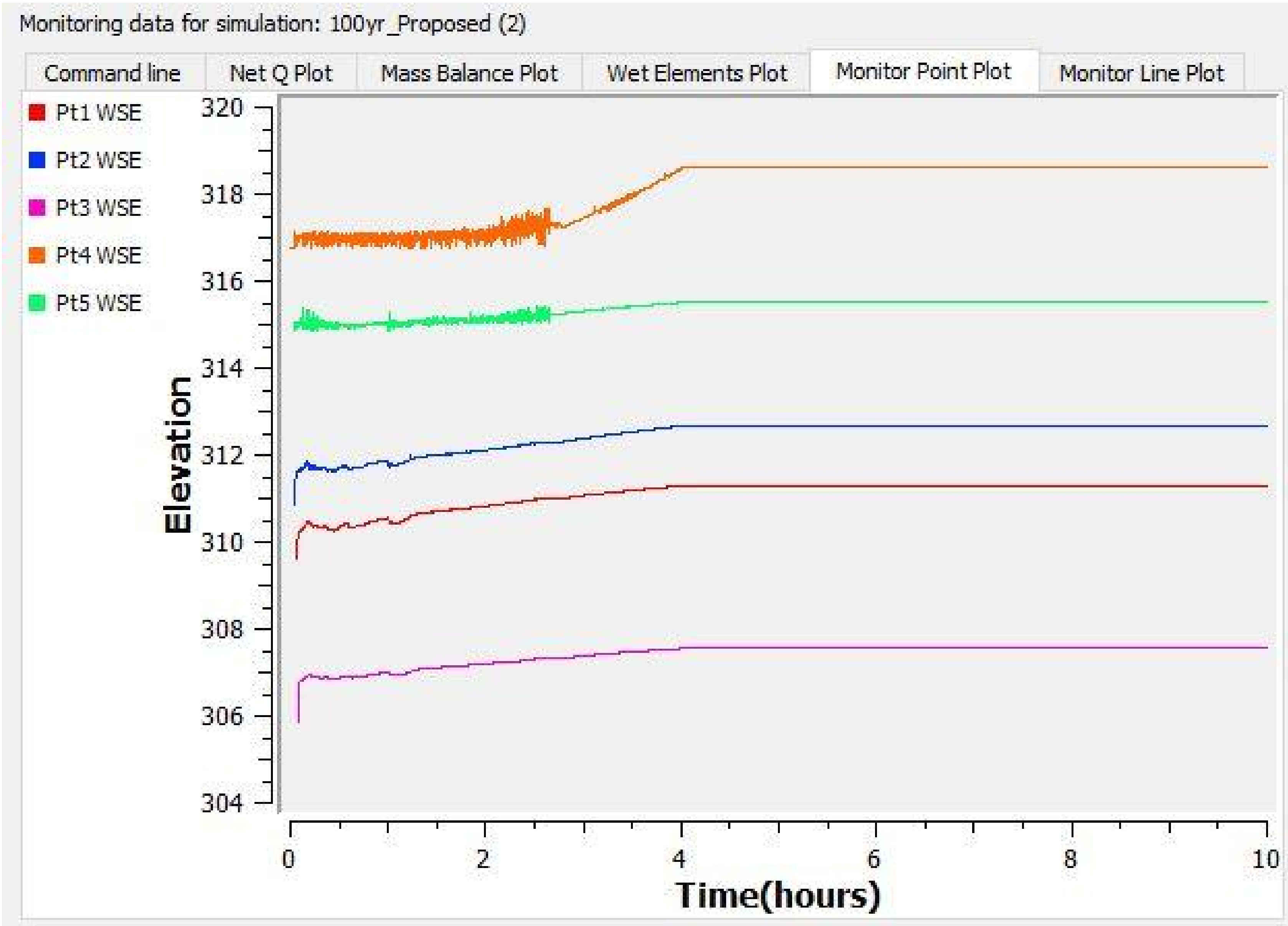


Figure I.13: Proposed conditions 100-year monitor points

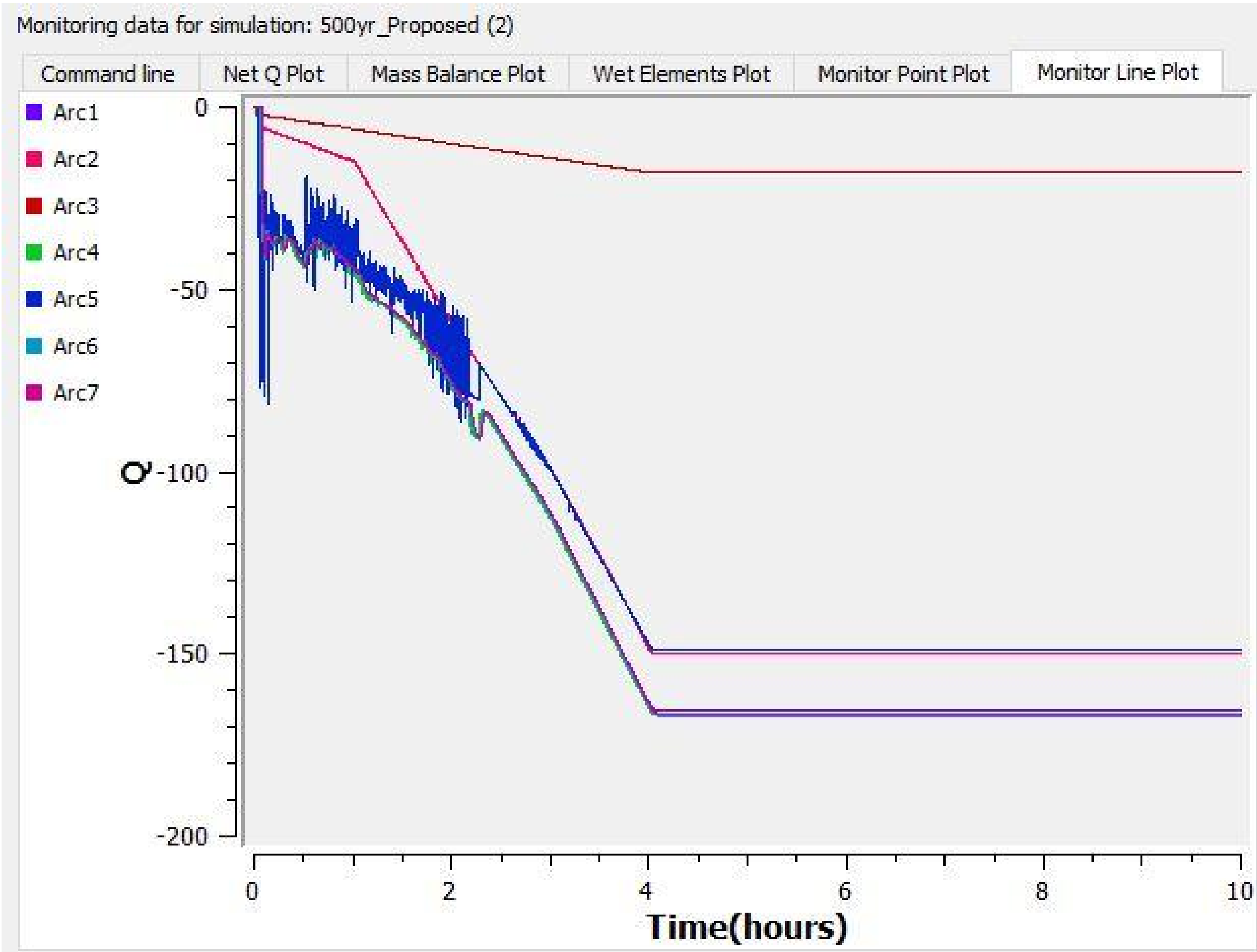


Figure I.14: Proposed conditions 500-year monitor lines

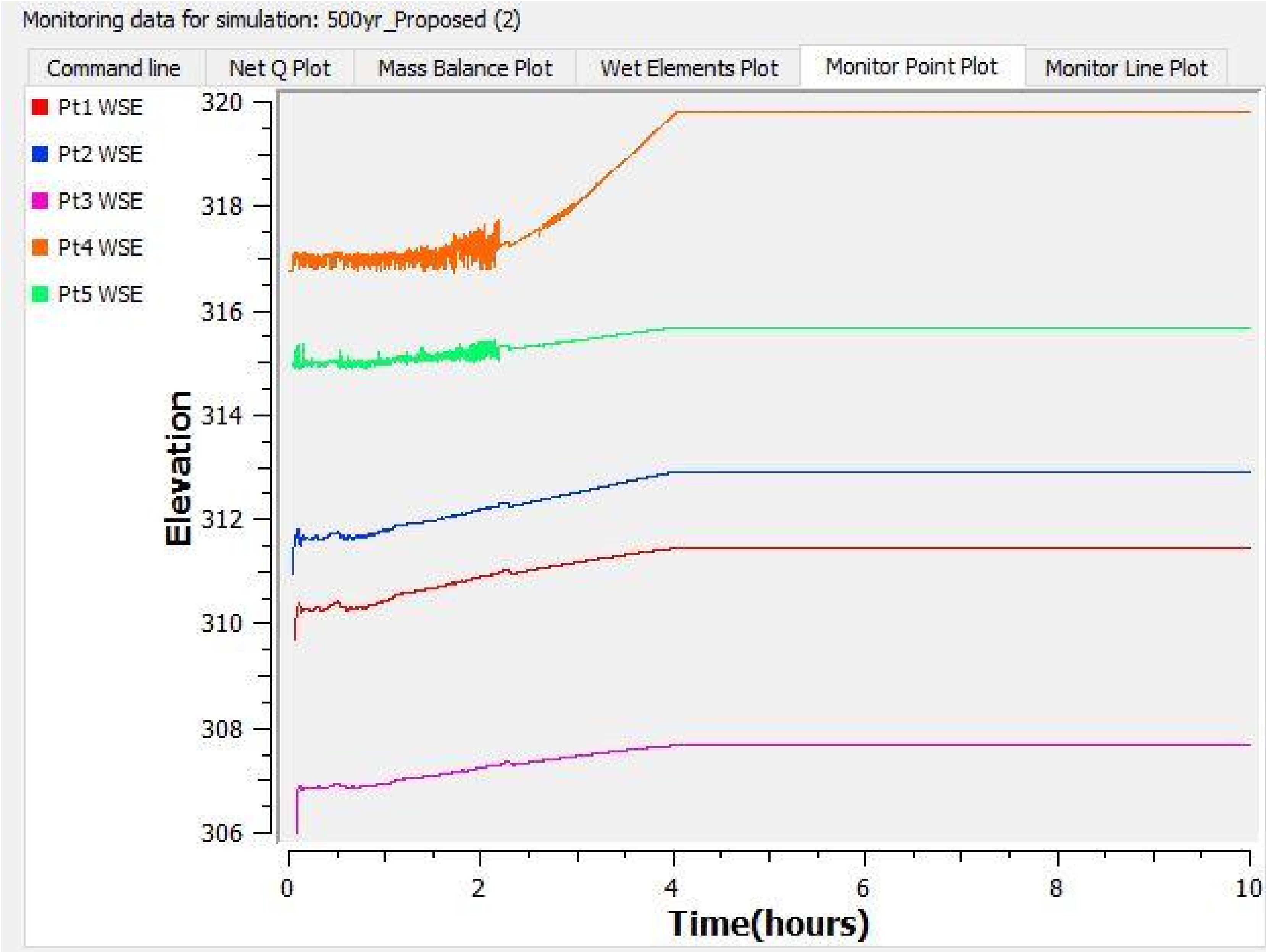


Figure I.15: Proposed conditions 500-year monitor points

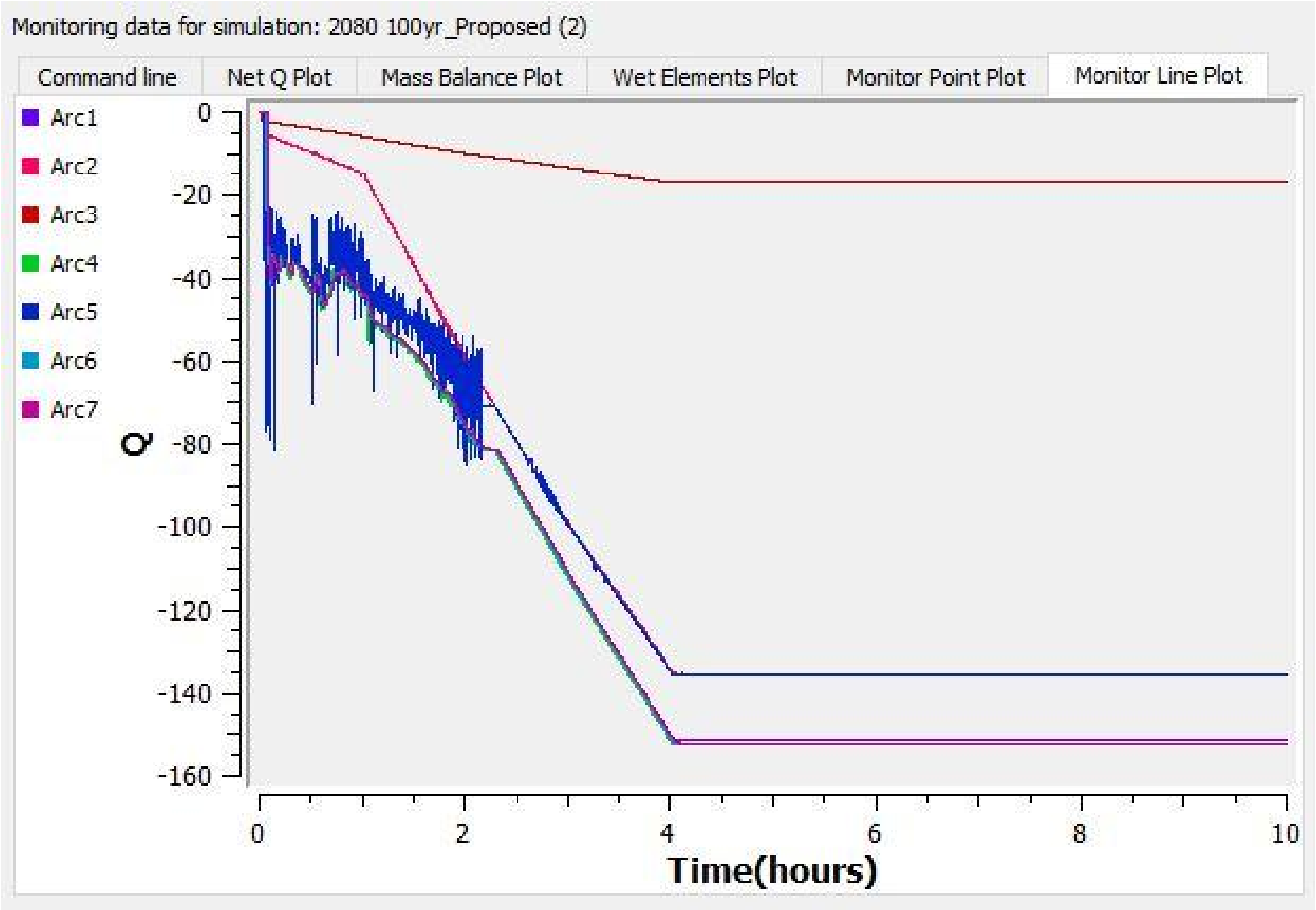


Figure I.16: Proposed conditions 2080 predicted 100-year monitor lines

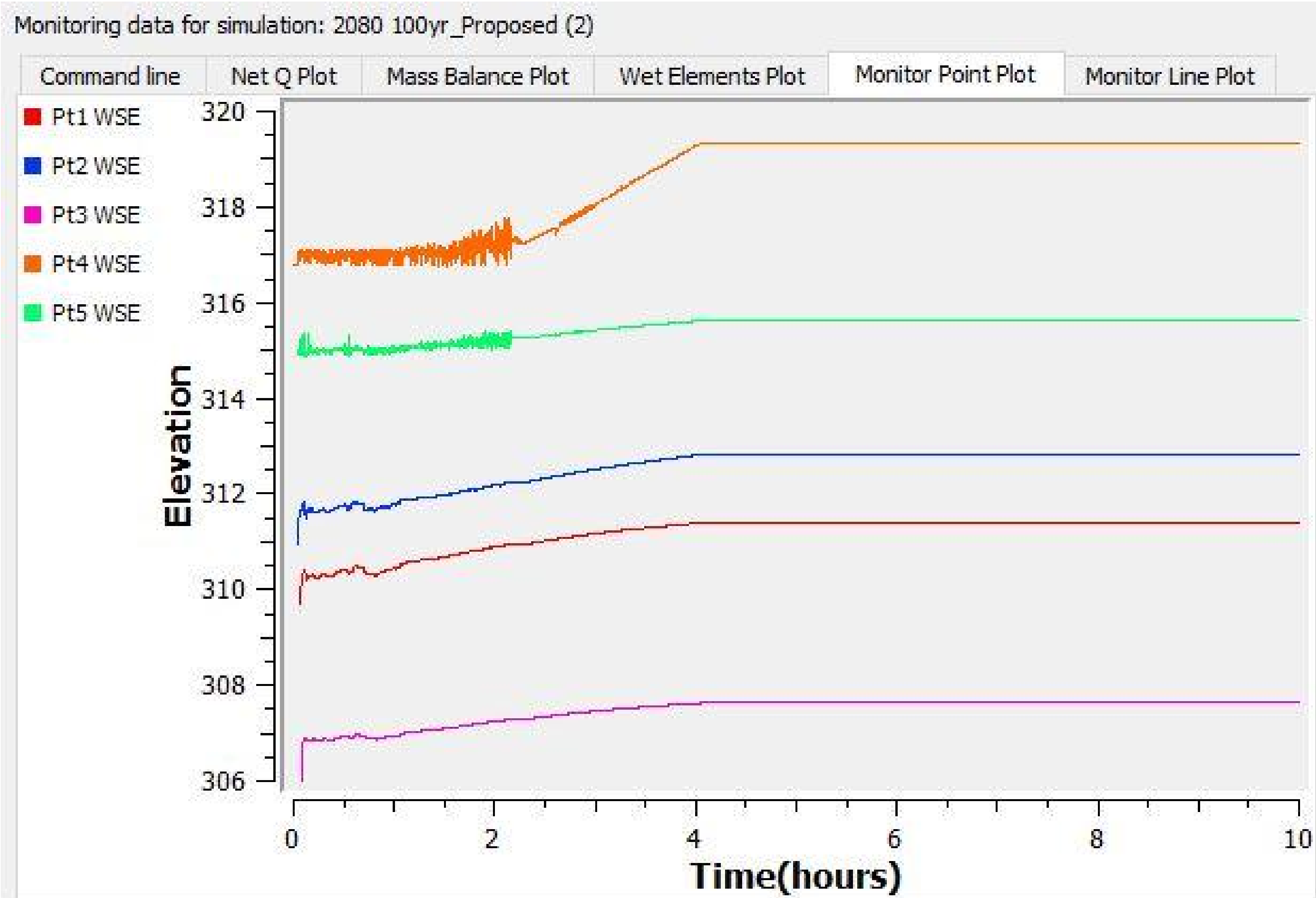


Figure I.17: Proposed conditions 2080 predicted 100-year monitor points

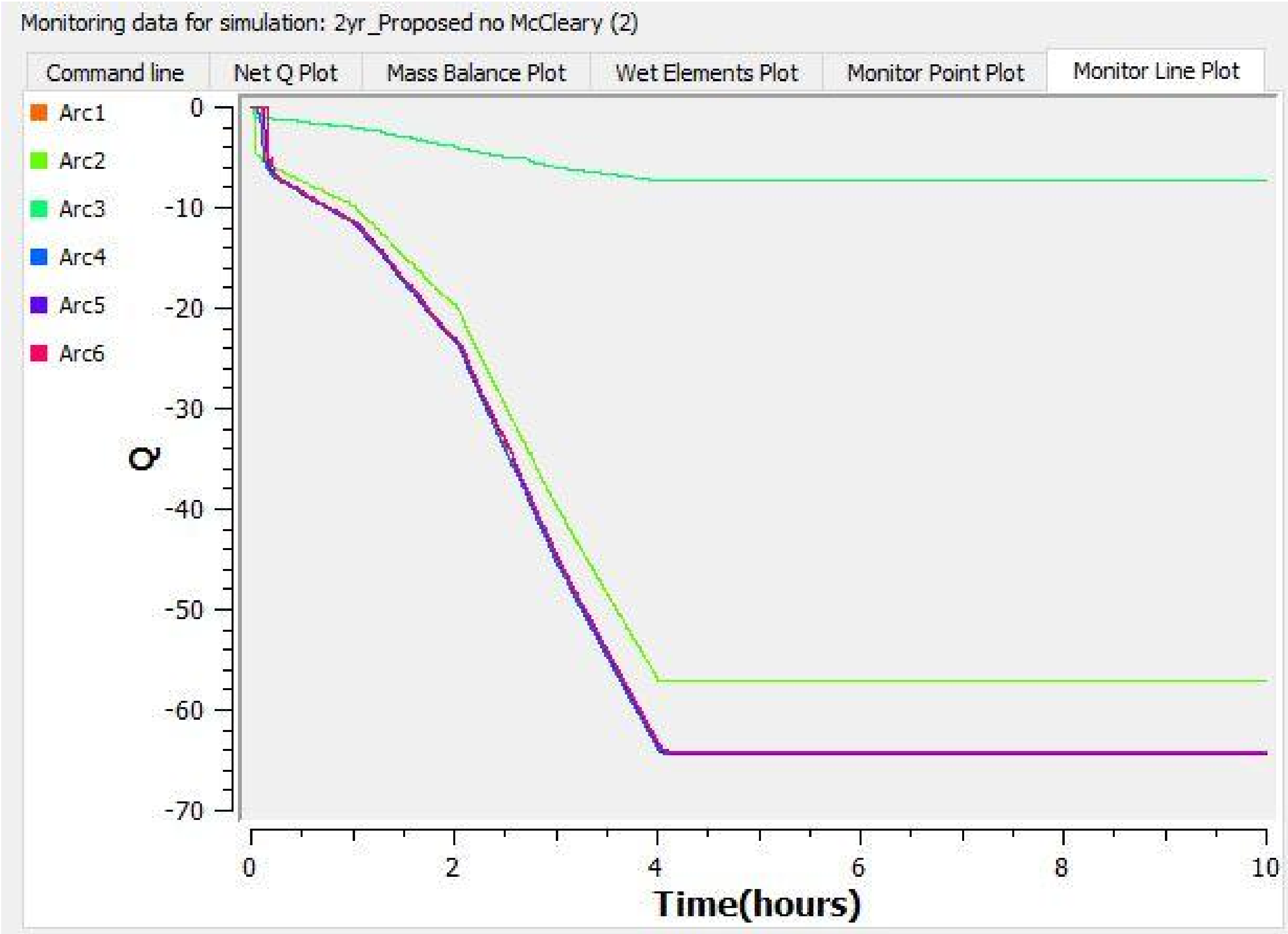


Figure I.18: Proposed conditions no McCleary Culvert 2-year monitor lines

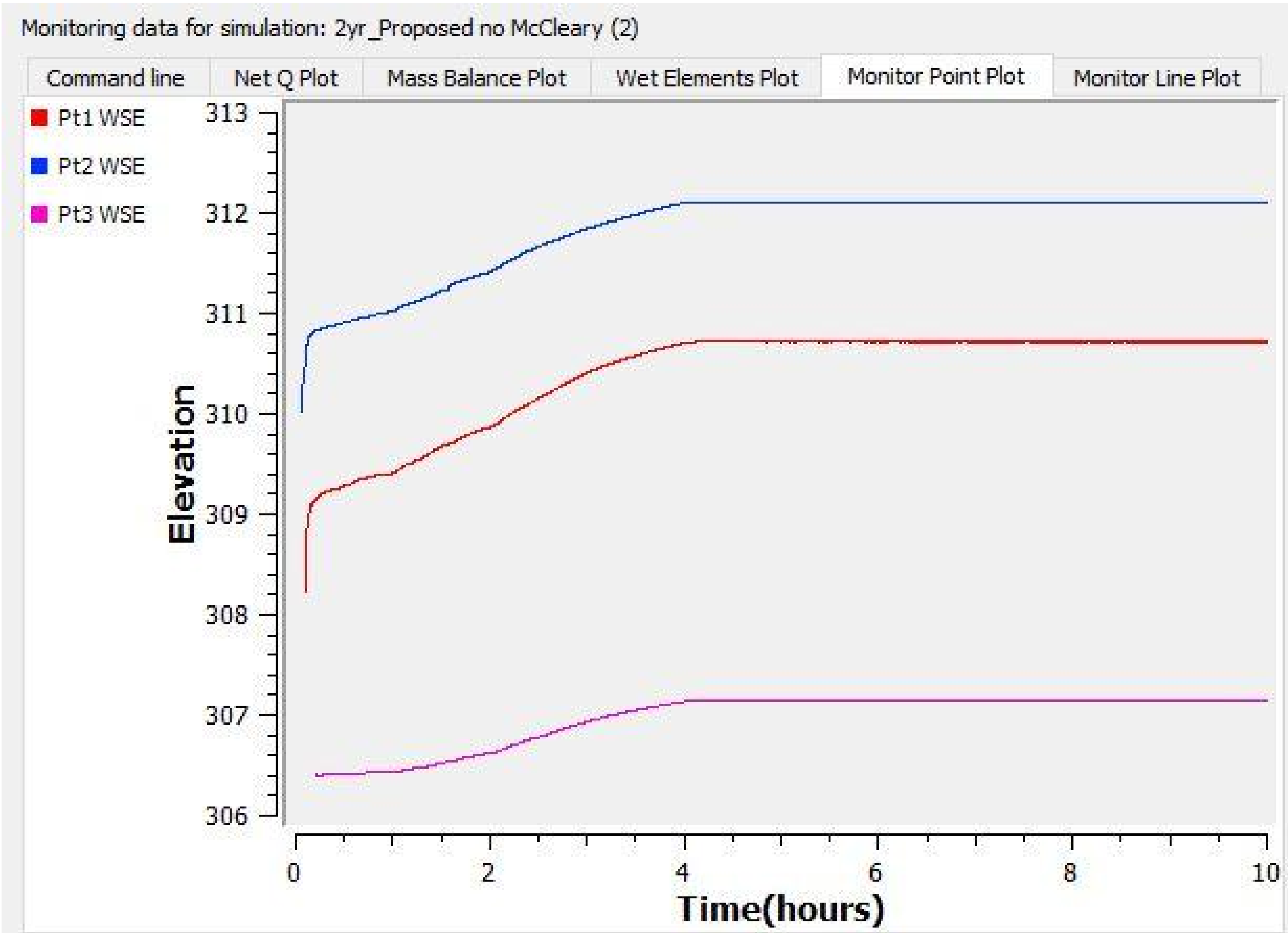


Figure I.19: Proposed conditions no McCleary Culvert 2-year monitor points

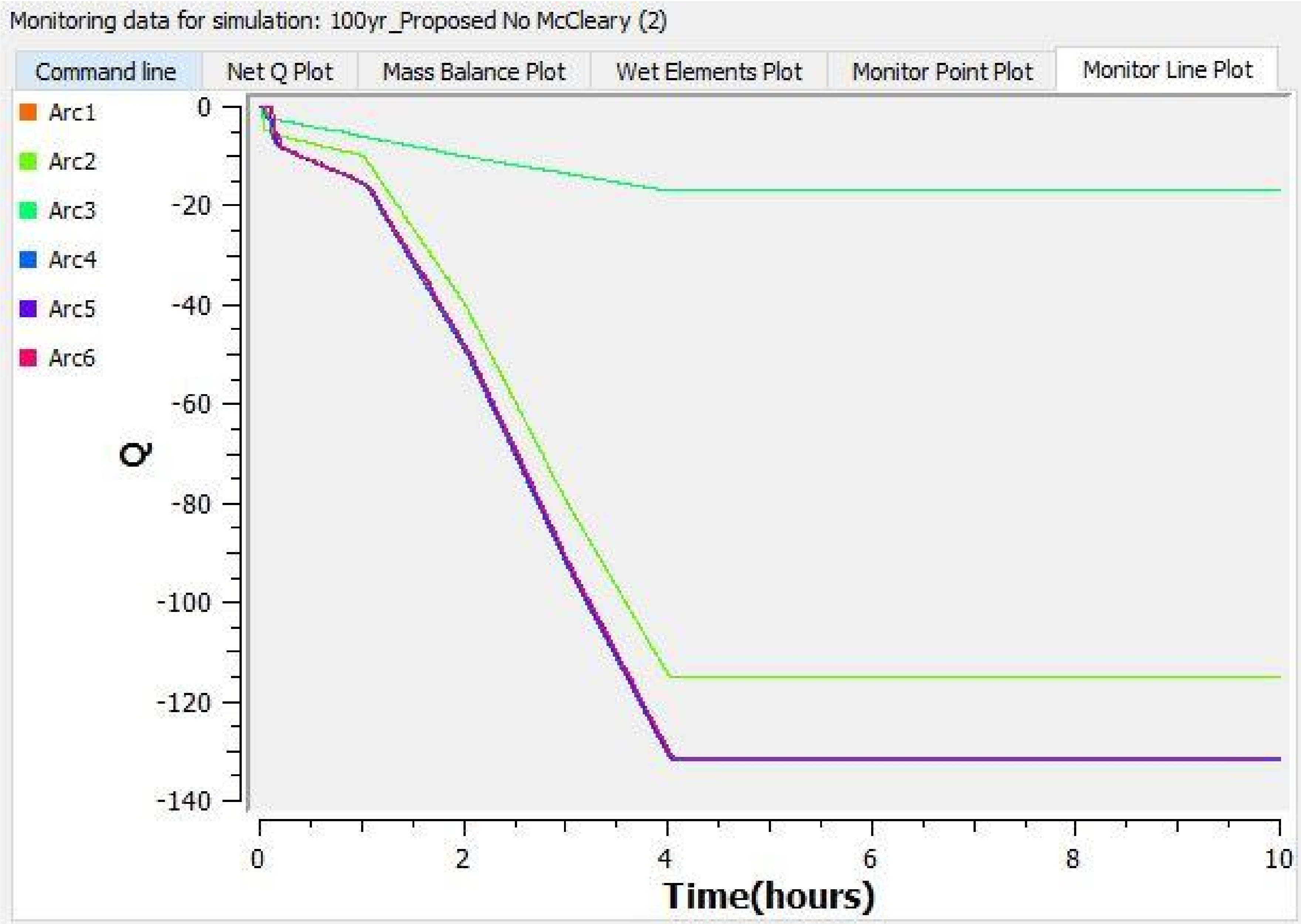


Figure I.20: Proposed conditions no McCleary Culvert 100-year monitor lines

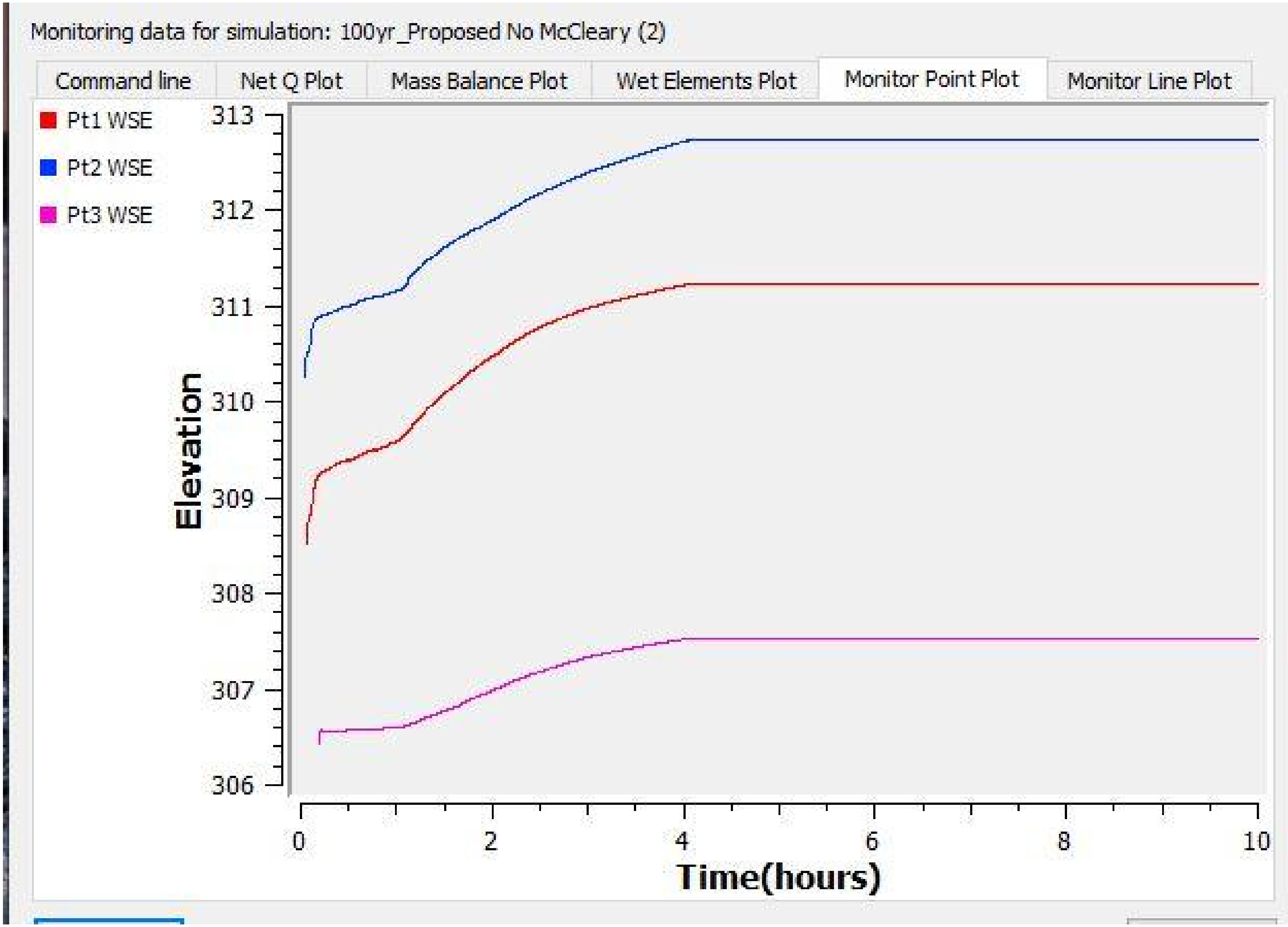


Figure I.21: Proposed conditions no McCleary Culvert 100-year monitor points

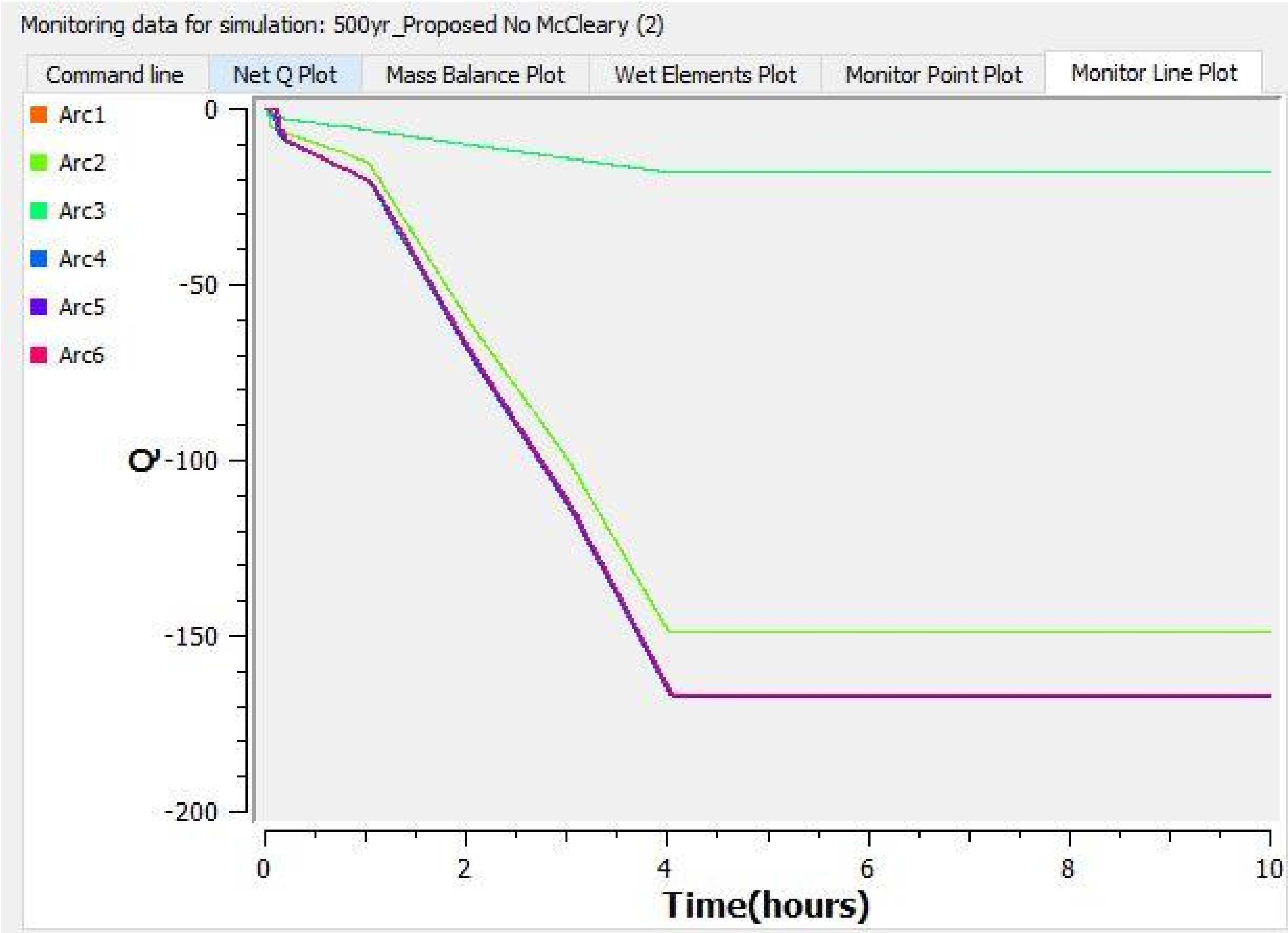


Figure I.22: Proposed conditions no McCleary Culvert 500-year monitor lines

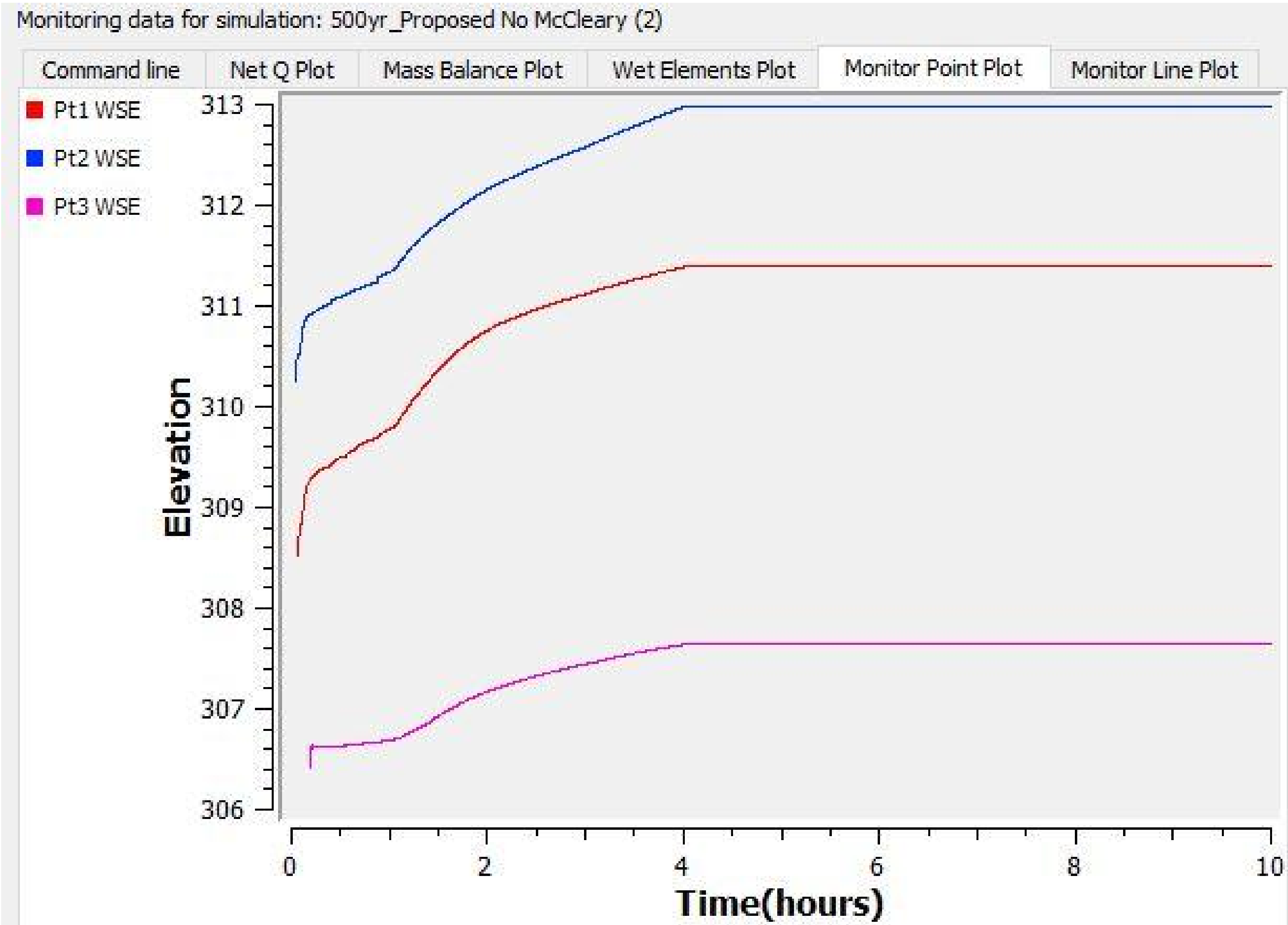


Figure I.23: Proposed conditions no McCleary Culvert 500-year monitor points

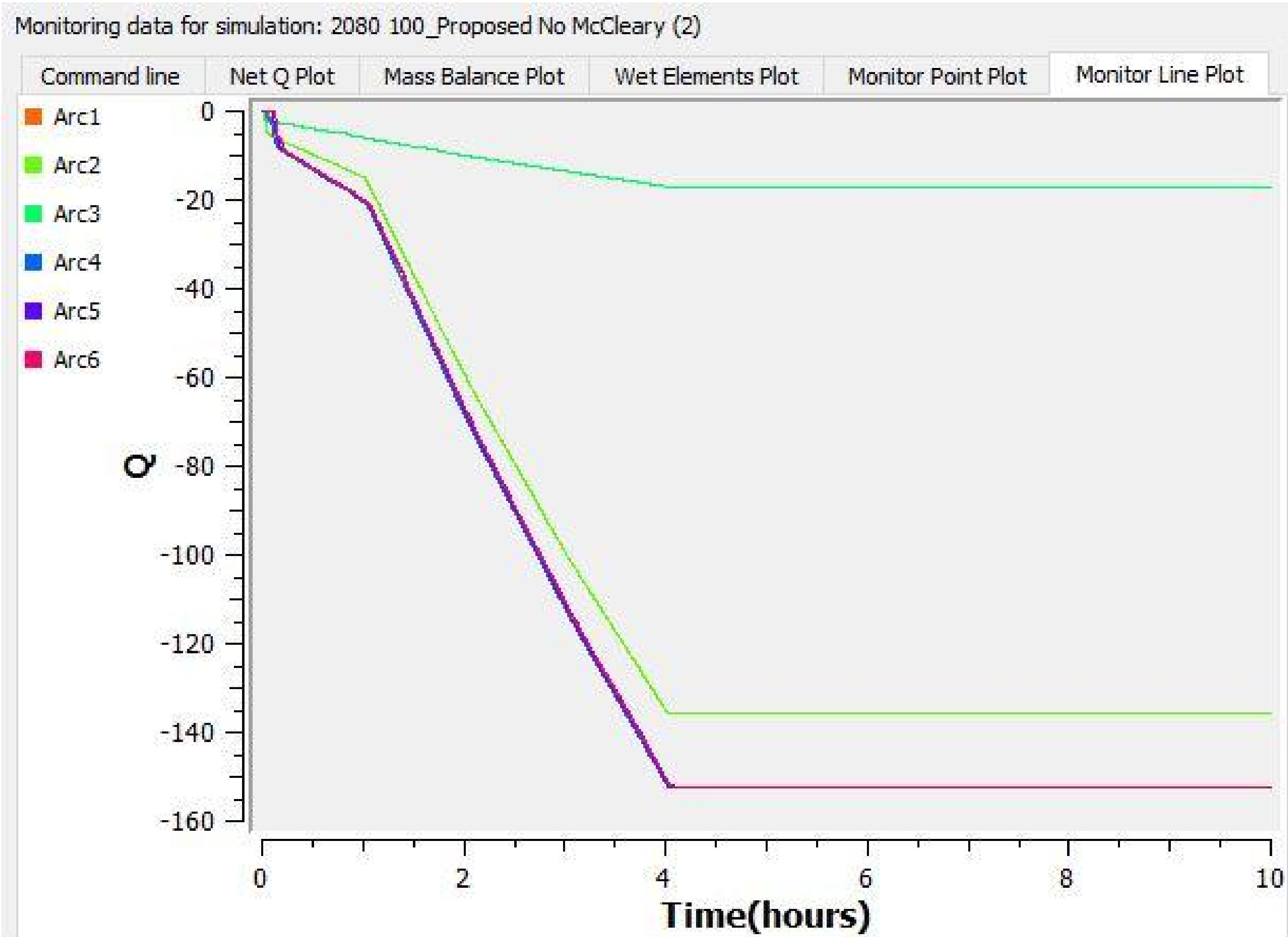


Figure I.24: Proposed conditions no McCleary Culvert 2080 predicted 100-year monitor lines

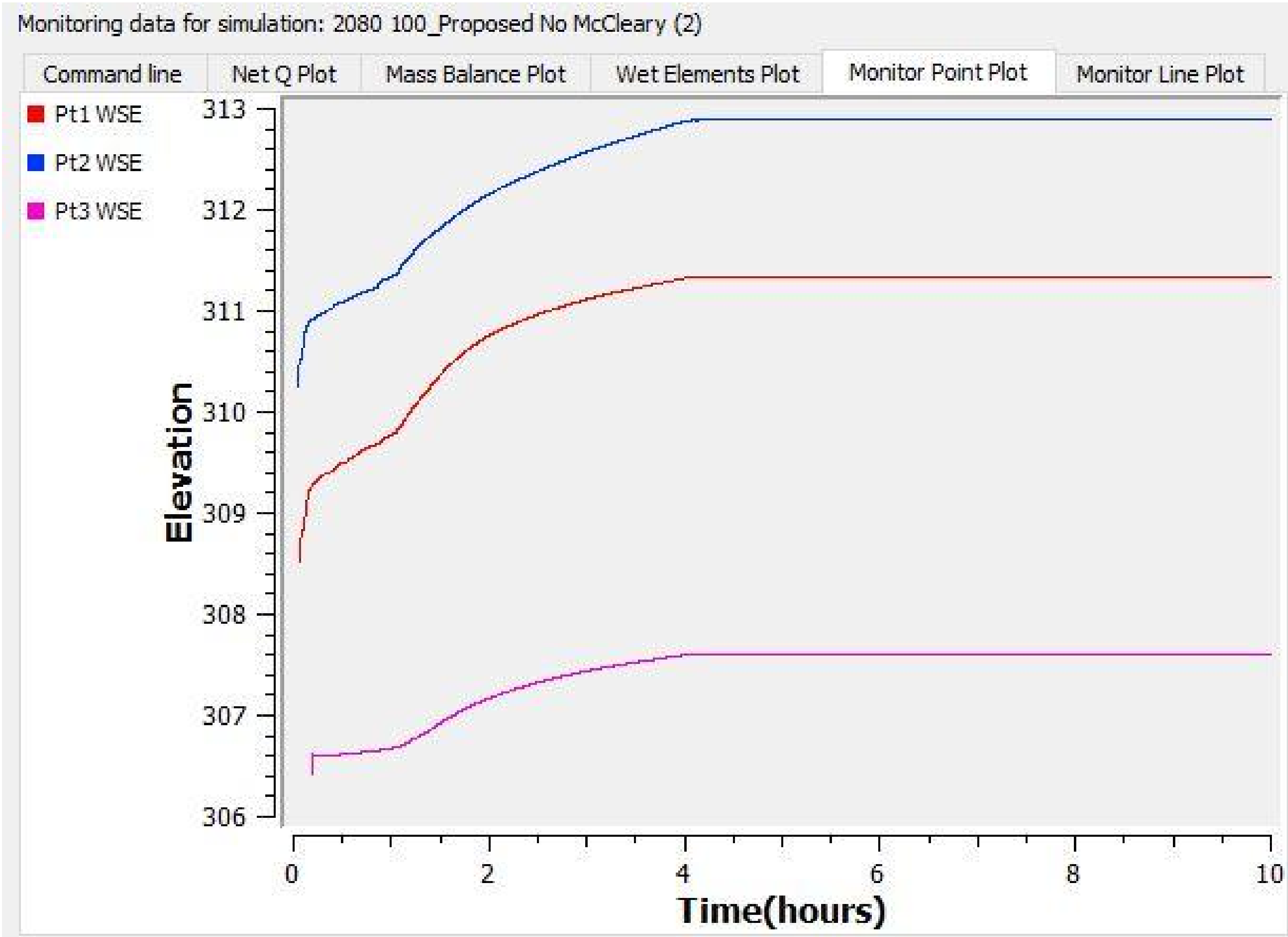


Figure I.25: Proposed conditions no McCleary Culvert 2080 predicted 100-year monitor points

Appendix J: Reach Assessment

Not Used

Appendix K: Scour Calculations

Scour in channel bend
Source: WDFW, App E

100 yr

Thorne Equation (for gravel beds)

$d = y_1[1.07 - \log(R_c/W-2)]$ for $2 < R_c/W < 22$

input data in blue:	value =	source
y_1 = average flow depth directly upstream of the bend (ft)	2	from SRH-2D
W = width of flow (bankfull for high flows) (ft)	16	from Plan Set
R_c = radius of curvature at channel centerline (ft)	25	measured from CAD

Calculated values:

		value =		
	R_c/W =	1.5625		**Check M**
maximum depth of scour below local stream bed elevation	d =	#NUM!	ft	

Maynard Equation (for sand beds)

input data in blue:	value =	source
R_c = Centerline radius of the bend, (ft,m)	25	measured from CAD
W = Width of the channel at the bend, (ft,m)	16	from SRH-2D
A = Cross sectional area upstream of bend (ft^2, m^2)	23.3	from SRH-2D
W_u = Channel width upstream of bend, (ft,m)	10	from SRH-2D
Dm = Measured water depth in bend, (ft,m)	2	from SRH-2D

D_{mnc} = Ave water depth in the cross section upstream of bend, (ft,m) 2.3

checks for valid use of this method:

1) Rc/W should be > 1.5	Rc/W =	1.6	**OK**
2) Rc/W should be < 10	Rc/W =	1.6	**OK**
3) Overbank depth should be less than 20% of main channel depth			

Computation:

$$Dmxb = Dmnc\left[1.8 - 0.051\left(\frac{Rc}{W}\right) + 0.0084\left(\frac{W}{Dmnc}\right)\right] = 4.1 \text{ feet (m)}$$

Scour Depth = 2.1 feet (m)
(Water depth at scour - Water depth w/o scour)

ethods

Hydraulic Analysis Report

Project Data

Project Title: MoxChehalis

Designer:

Project Date: Wednesday, February 9, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:Scour_100-Year-u/s

Notes:

Scenario: Scour Scenario

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 1.23 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 1.23 ft

Clear Water Contraction Scour Depth 1.23 ft

Live Bed Contraction Scour Depth -0.40 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -1.14 ft

Total Scour at Abutment 0.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.55 ft

D50: 38.000026 mm

Average Velocity Upstream: 3.29 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 6.00 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 132.00 cfs

Bottom Width in Contracted Section: 4.00 ft

Depth Prior to Scour in Contracted Section: 3.00 ft

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0273 ft/ft

Flow in Contracted Section: 132.00 cfs

Flow Upstream that is Transporting Sediment: 132.00 cfs

Width in Contracted Section: 4.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 3.00 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.500032 mm

Average Depth in Contracted Section after Scour: 4.23 ft

Scour Depth: 1.23 ft

Results of Live Bed Method

Shear Velocity: 1.17 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 2.60 ft

Scour Depth for Live Bed: -0.40 ft

Shear Applied to Bed by Live-Bed Scour: 3.6045 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4989 lb/ft^2

Recommendations

Recommended Scour Depth: 1.23 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 33.00 cfs/ft

Unit Discharge in the Constricted Area (q2): 33.00 cfs/ft

D50: 38.000026 mm

Upstream Flow Depth: 1.55 ft

Flow Depth Prior to Scour: 3.00 ft

Result Parameters

q2/q1: 1.00

Average Velocity Upstream: 21.29 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 6.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.55 ft

Maximum Flow Depth including Abutment Scour: 1.86 ft

Scour Hole Depth from NCHRP Method: -1.14 ft

Bridge Scour Analysis:Scour_500-Year-u/s

Notes:

Scenario: Scour Scenario

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 1.99 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 1.99 ft

Clear Water Contraction Scour Depth 1.99 ft

Live Bed Contraction Scour Depth -0.96 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -0.96 ft

Total Scour at Abutment 0.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.86 ft

D50: 38.000026 mm

Average Velocity Upstream: 3.73 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 6.19 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 167.00 cfs

Bottom Width in Contracted Section: 4.00 ft

Depth Prior to Scour in Contracted Section: 3.19 ft

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0272 ft/ft

Flow in Contracted Section: 167.00 cfs

Flow Upstream that is Transporting Sediment: 167.00 cfs

Width in Contracted Section: 4.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 3.19 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.500032 mm

Average Depth in Contracted Section after Scour: 5.18 ft

Scour Depth: 1.99 ft

Results of Live Bed Method

Shear Velocity: 1.28 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 3.13 ft

Scour Depth for Live Bed: -0.06 ft

Shear Applied to Bed by Live-Bed Scour: 4.2575 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4989 lb/ft^2

Recommendations

Recommended Scour Depth: 1.99 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 41.75 cfs

Unit Discharge in the Constricted Area (q2): 41.75 cfs/ft

D50: 38.000026 mm

Upstream Flow Depth: 1.86 ft

Flow Depth Prior to Scour: 3.19 ft

Result Parameters

q2/q1: 1.00

Average Velocity Upstream: 22.45 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 6.19 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.86 ft

Maximum Flow Depth including Abutment Scour: 2.23 ft

Scour Hole Depth from NCHRP Method: -0.96 ft

Bridge Scour Analysis:Scour_2080 100-Year -u/s

Notes:

Scenario: Scour Scenario

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Applied Contraction Scour Depth 1.68 ft

Contraction & Long Term Scour is applied method due to greater scour.

Pressure Scour Depth 1.68 ft

Clear Water Contraction Scour Depth 1.68 ft

Live Bed Contraction Scour Depth -0.08 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth -1.03 ft

Total Scour at Abutment 0.00 ft

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.73 ft

D50: 38.000026 mm

Average Velocity Upstream: 3.53 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 6.11 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 152.60 cfs

Bottom Width in Contracted Section: 4.00 ft

Depth Prior to Scour in Contracted Section: 3.11 ft

Temperature of Water: 40.00 ºF

Slope of Energy Grade Line at Approach Section: 0.2696 ft/ft

Flow in Contracted Section: 152.60 cfs

Flow Upstream that is Transporting Sediment: 152.60 cfs

Width in Contracted Section: 4.00 ft

Width Upstream that is Transporting Sediment: 9.00 ft

Depth Prior to Scour in Contracted Section: 3.11 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.500032 mm

Average Depth in Contracted Section after Scour: 4.79 ft

Scour Depth: 1.68 ft

Results of Live Bed Method

Shear Velocity: 3.88 ft/s

Fall Velocity: 1.64 ft/s

Average Depth in Contracted Section after Scour: 3.03 ft

Scour Depth for Live Bed: -0.08 ft

Shear Applied to Bed by Live-Bed Scour: 3.7491 lb/ft^2

Shear Required for Movement of D50 Particle: 0.4989 lb/ft^2

Recommendations

Recommended Scour Depth: 1.68 ft

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 38.15 cfs

Unit Discharge in the Constricted Area (q2): 38.15 cfs/ft

D50: 38.000026 mm

Upstream Flow Depth: 1.73 ft

Flow Depth Prior to Scour: 3.11 ft

Result Parameters

q2/q1: 1.00

Average Velocity Upstream: 22.05 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 6.11 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.20

Flow Depth including Contraction Scour: 1.73 ft

Maximum Flow Depth including Abutment Scour: 2.08 ft

Scour Hole Depth from NCHRP Method: -1.03 ft

Appendix L: Floodplain Analysis

Not Used. A floodplain risk assessment was not required at this location.